The EMPIRE JOURNAL of EXPERIMENTAL AGRICULTURE

VOLUME XXII

OXFORD
AT THE CLARENDON PRESS
LONDON: GEOFFREY CUMBERLEGE
1954

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MILK RECORDING AND THE USE OF MILK RECORDS IN DAIRY STOCK IMPROVEMENT IN ENGLAND AND WALES[1]

E. D. ASHTON

(*Bureau of Records, Milk Marketing Board*)

MILK recording in this country has long been carried out by individual breeders but official milk recording did not begin until 1904. Scotland led the way, and it was another ten years before the movement started in England and Wales.

Here, official milk recording began as a part of the Ministry of Agriculture's 'Livestock Improvement Scheme' in 1914, and the first milk-recording society was formed in April of that year. In the earliest years of the movement the fundamental part that milk recording plays in dairy stock improvement was clearly recognized, and in the critical days of the First World War the Astor Committee [1] wrote:

> Under the Live Stock Improvement Scheme of the Boards of Agriculture, a considerable number of Milk Recording Societies have been established. It has not taken long for the farmers who joined these to realise the advantages to be derived from keeping accurate records of the milk yield and the effect upon it of various methods of feeding, with the result that the demand for the formation of such Societies is increasing rapidly, and their increase is only hampered by shortage of staff. While fully realising the difficulty which an increase of staff in any department now presents, the Committee considered that the extension and development of the practice of milk recording was a matter of such importance for the dairying industry that they were justified in urging the Boards of Agriculture to make such additions to their staffs, and, in the case of England, to give such additional assistance to the Livestock Officers in the different provinces as were necessary to facilitate the formation of Societies wherever the farmers desired to have them.
>
> They also urged that the five year grants made to Societies in 1914 for milk recording and the improvement of dairy livestock generally should be continued.

By the end of the First World War, thirty eight societies—local groups of one or more recorders' circuits—covering 1,332 herds of 38,000 cows, were in operation. Each society, when it was formed, received a small Government grant of about £3 per herd, which was reduced gradually as the society gained strength. The movement penetrated in the next ten years to almost every county in the country, but the main strength was concentrated in the south and east. After a period of stability and consolidation between 1925 and 1930, when about 5,000 herds and 150,000

[1] An account of the work of the Production Division, complementary to that on artificial insemination described by Dr. J. Edwards, Head of the Production Division, Milk Marketing Board (England and Wales), in *Empire J. Expt. Agric.*, 1947, **15**, 149–59.

[Empire Journ. of Exper. Agric., Vol. 22, No. 85, 1954.]

cows were recorded, a slight decline took place in the depression years of the thirties.

At the outbreak of war in 1939 Government support was withdrawn and the emphasis given to a crop, as distinct from a stock, economy reduced membership still further, especially in the north and west of the country, where herds were small. At the end of 1942 only 4,000 herds were recorded—these contained 125,000 cows, or about 5 per cent. of the total dairy-cattle population.

Between 1939 and 1942 there was a serious fall in milk output and, in view of the necessity for maintaining supplies of so valuable a food, milk was classed as a product of No. 1 priority in the Government's

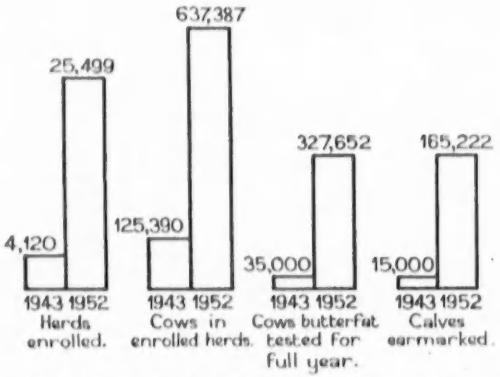


FIG. 1. Some features of progress in the milk-recording movement

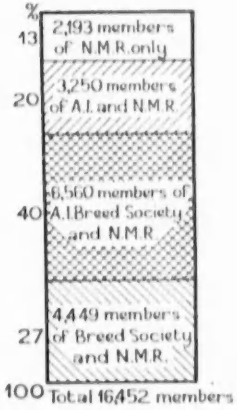
agricultural programme. As part of the campaign to increase production, the Milk Marketing Board—a producers' organization, formed in 1933 to market on a collective basis all milk sold off farms in England and Wales—was asked to take over responsibility for the milk-recording movement. The immediate task was to extend milk recording among the dairy farmers, and since January 1943, when the Board became responsible for the development of the movement, 21,000 herds have been added to the list of recorded herds. The movement was named National Milk Records. There are now forty-seven societies or branches and about one-quarter of the dairy-cattle population is recorded. The extent of the progress made in the ten years 1943–52 is shown in Fig. 1.

The Milk-Recording Movement Today

National Milk Records now consists of a single official scheme, within which members can weigh either weekly or daily (three out of four choose the former). Members may also test for fat content if they wish, and three out of four members receive this service. The sample for testing is taken by the Recorder, on the occasion of his official visit to the

herd, which is at intervals of 6 weeks for fat-tested herds and of 8 weeks for non-butterfat-tested herds. Each branch has its own elected committee, which advises the Board on milk recording in its area. A National Advisory Committee (which is composed of representatives of the Board, the Branches, the Ministry of Agriculture, the Dairy Breed Societies, the National Farmers' Union, and to which are co-opted scientists interested in cattle breeding) in turn guides the Board on policy.

There is still scope for expansion, particularly in the main dairying areas, where only 10 per cent. of the herds are recorded compared with about 50 per cent. in the south-east, and many members of Dairy Breed Societies are still outside the milk-recording movement.



Note.—The counties of Cambridgeshire and District, Norfolk, Suffolk, Warwickshire, Herefordshire, Worcestershire, Denbighshire and Flintshire, Merionethshire, Berkshire, Hampshire, Oxfordshire, Isle of Wight, Somerset, Devon, Hertfordshire, Middlesex, and Surrey, are excluded because they are either wholly or partly covered by non-Board centres, and full information was not available for these counties. The proportion of recording members who are also members of Breed Societies only (bottom category in the diagram) is higher in these counties than in the rest of the country, so that for England and Wales the figure corresponding to 27 per cent. is 35 per cent. The combined figure of the third and fourth categories, however, for England and Wales is 65 per cent. compared with 67 per cent. shown here.

FIG. 2. Membership of National Milk Records in the Board's A.I. Areas

The expansion in the last decade has, however, been considerably stimulated by a simultaneous expansion in membership of Dairy Breed Societies, which created a demand for a milk-recording service for these societies, whose various merit schemes were based on official milk records. Latterly there has been added the stimulus of the rapid expansion in artificial insemination. All three movements have progressed together to the extent that all are very closely linked. Now the great majority of the 25,000 recorded herds are members of Dairy Breed Societies or of A.I. centres. Many of course belong to both, and Fig. 2 illustrates the importance of recorded herds in the Board's A.I. movement.

There is, therefore, a close identity of interest between the recording and breeding movements and on this foundation clearly rest all plans for further improvements in the country's dairy stock.

The Bureau of Records.

In order to facilitate the use of information for dairy stock improvement, the Bureau of Records was formed in 1946. Thus has been realized

one of the most important recommendations of the Astor Committee, set out in their final report [2] in the following terms:

> *Study of the Information collected by Milk Record Societies necessary.*—The Milk Record Societies accumulate much varied information as to local methods of management. The Committee believe that the interest of farmers in milk records would be stimulated, and that the systems of management in different districts would be considerably improved if an analysis of the results obtained by a society or group of societies were made available to the dairy farmers concerned.

By 1952 a million lactation records of registered cattle had been assembled in the Bureau besides much reliable information on the non-pedigree cattle in the recording movement. In 1952 350,000 records were supplied to meet requests from the Dairy Breed Societies and A.I. organizations, individual breeders, and research and advisory workers, for their particular needs in their work on livestock improvement. Furthermore, through the organization of the Bureau, progeny recording on a national basis has become a reality and information useful to breeders is being distributed in the various published reports. The Bureau assists the Board's Advisory Committee on milk recording which from year to year examines the standards used in these publications, which circulate widely to the membership of the milk-recording movement. Apart from the direct function which the publications have of keeping membership informed, they are used as a pattern for other activities such as shows, sales, and competitions. It is the Board's opinion that interest in milk recording is well sustained by these publications and care is taken in their preparation and in making improvements and refinements to assist breeders in the interpretation of results contained in them.

Breed Structure of the National Herd

A fund of knowledge is being built up about the foundation stock of dairy cattle of this country and wide use is already being made of it. Certain developments have made the Bureau's work necessary and its services extensive. In the inter-war period dairying had been stimulated by the better return it gave than other lines of farming, and subsequently during the war this stimulus was strengthened by Government policy so that production of milk for sale now dominates our agriculture. Among the many changes which this development has brought about, that of breed pattern is one of the most important. While the number of breeds in this country remains at about a score if all are included—beef and dairy and dual purpose—their relative importance has undergone remarkable change. Unfortunately since 1908 no census returns of cattle by breed type are available, but it is interesting to note that at that time two-thirds of the cattle of Great Britain were described as Shorthorn and the next in importance were Devon, Ayrshire, Hereford, Welsh Black, Aberdeen Angus, and Irish (for England and Wales alone the Ayrshire and Angus would be replaced by the Lincoln Red Shorthorn and Channel Island). Fig. 3 attempts to show the breed distribution at three dates in the past fifty years.

Looking to the future and using as a basis the breed demand figures

in the A.I. movement (which now covers about 40 per cent. of our cattle) the breed distribution might soon be of the following order:

Beef = 14 per cent. Dual purpose = 24 per cent. Dairy = 62 per cent.

The background is, therefore, one of continuous change.

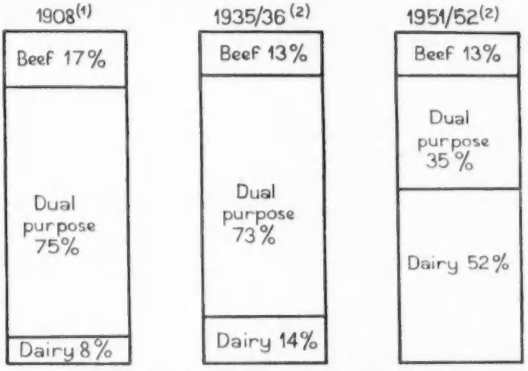


FIG. 3. Estimated breed distribution

Beef = Aberdeen Angus, Devon, Galloway, Hereford, Highland, and Sussex
Dual purpose = Shorthorn and all other breeds
Dairy = Ayrshire, Friesian, Guernsey, and Jersey

Note: 1. 1908: based on Ministry of Agriculture Census—Great Britain.
2. 1935/6 and 1951/2: based on the Ministry of Agriculture's Bull Licensing figures for England and Wales. These figures tend to reflect the position slightly ahead of date.
3. Sales of milk off farms (million gallons): 1908 = 700; 1935/6 = 1,100; 1951/2 = 1,500.

Bull Selection and the Use of the Progeny Test

Great progress in performance has already been made in the dairying industry, in that now twice as much milk is being made available to urban consumers as fifty years ago, and the average yield per cow on dairy farms is about 100 gallons higher than the best pre-war figure. Some of it is due no doubt to the change of breed pattern. As far as dairy stock improvement is concerned, the problem today is, as always, to mate the best to the best on as wide as possible a basis. The male side offers—particularly under present conditions of rapid A.I. development—great scope for improvement in so far as a single bull can influence the next generation to a far greater extent than a single cow. The three national organizations, the Board, the Ministry of Agriculture, and the Dairy Breed Societies have consequently concentrated their dairy stock improvement plans on finding better bulls, although the Dairy Breed Societies by their very nature must look after the female side with equal concern. In the last decade the number of bulls used in England and Wales has fallen steadily from 107,000 to 77,000 and with this reduction has come a steady elimination of the bull

of unknown breeding. The present position is that only one-sixth of the bulls used now are of unknown breeding compared with two-thirds ten years ago. Here is a challenge to those responsible for the selection of these animals and, simultaneously, a better basis for future progress than has ever existed before.

The progeny test is regarded as the best-known method of assessing breeding worth and it is here that milk records linked with breeding records through the organization of the Bureau play a vital part. Of the 50,000 bulls, dead and alive, on the Bureau's files, nearly 10,000 have sufficient daughters (ten is a reasonable figure) to give a test which can be regarded as the starting-point for a considered evaluation of breeding worth in the National Milk Records Report for England and Wales. About 2,500 of these are selected for publication in each year, the selection being based on the standard that the daughter average must exceed the average of the breed by 10 per cent. Here then is an important step forward in dairy-stock improvement, based on progeny recording on a national basis; this information is being disseminated widely throughout the country.

Breed societies have followed this up with particular emphasis and added refinements for their individual breeds, and private breeders are using this material in ever-increasing numbers. However carefully these records are prepared and arranged and however cautiously general results are interpreted, each breeder must work out his own plan and must find out for himself the conditions under which the results of the progeny test have been made. There are formidable problems in the use of the progeny test. It is doubtful if we can ever have in dairy-cattle breeding the advantages of the plant breeder in the extent of control over his material and the relative cheapness of his methods, but by study and research some of the inherent defects which are inevitable in cattle breeding work can be reduced, or at least explained. The most important of these is, of course, the problem of the relative influence of environment and breeding.

Throughout the world scientists are giving this close attention and they have developed in each country the techniques best suited to its needs in studying the problem. The Danish Bull Testing Station is an example of this, and the Dutch method applied to the progeny-test technique can best be seen in the extremely careful basis of assessment contained in the Dutch Preferent Bull Scheme. Similarly, in New Zealand and North America, the progeny test is subject to most careful study under the conditions prevailing in these countries. In all countries the problem is being dealt with by the closest co-operation between the breeding and recording movements. Here, where these two movements are very close, the Board have a special responsibility. They have, however, in their progeny-testing plan made the most of their opportunity in that they have charge of the two movements and can plan breeding to ensure the availability of the kind of information required. In addition, they have tried to incorporate into their own plans that overseas work which is best and most suitable according to the conditions here. Since 1949 they have developed a plan to progeny-test young bulls in A.I. based on planned

matings in selected herds. More recently they are co-operating in an experiment to set up an English counterpart of a Danish Bull Testing Station project.

Other Uses of Milk Records

Whatever progress we may be able to make in the use of the progeny test, it must not be at the expense of continued attention to the female side nor at the cost of neglecting those problems which are the constant

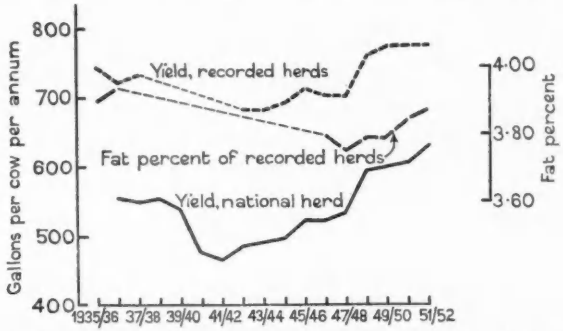


FIG. 4. Changes in milk yield per cow and in fat content since 1935.

Note: 1. Different methods of calculating yield for recorded herds and for the national herd slightly favour the former. The difference between them has narrowed because now a quarter of the national herd is recorded compared with 5 per cent. in 1942/3.

2. Fat per cent. for recorded herds in pre-war days was based on the very few cows butterfat tested and it is to be noted that the proportion of Friesian to total butterfat-tested cows is now 33 per cent. compared with 25 per cent. before the war. Figures for the three main breeds are:

	1934/5 *% fat*	*1951/2* *% fat*
Ayrshire . . .	3·71	3·87
Friesian . . .	3·26	3·52
Shorthorn . .	3·56	3·61

concern of milk producers on the farm. Commercial milk production, after all, is the business of about 150,000 herd owners, most of them small. While the Board, the Breed Society, and the Ministry of Agriculture may relieve the herd owner of many of his problems in the choice of a bull, his main concern is still to get better results from his cows and breeding is only one side of the problem. Apart from supplying organizations, including research institutes, with information for their work on breeding problems connected with dairy stock, the Bureau of Records is able in a small way to investigate certain problems and in the annual reports of the Production Division some of the results of these investigations have been published [3–19]. These include studies of the influence of age at first calving on subsequent performance, of the relationship between fat content and yield at different levels, of the shape of lactation curves according to season of calving and age of cow, and of

seasonality of calving and its effect, along with other factors, on milk output.

Investigational work in the Bureau has shown that in terms of yield and also of fertility (ability for regular calving), the evidence is in favour of the early starter, at least in the better-than-average managed herds. It would be reasonable to apply this more widely and to state that if the national herd were managed up to this standard, greater intensity of production would be obtained, not only in terms of yield but also in terms of conserving livestock, by starting dairy cows on their productive life sooner and by so doing releasing stock resources for other lines of production, like beef, which the country needs. Investigations have also indicated that there is no incompatability, except possibly at very high levels of yield, between high milk and satisfactory fat content; and it seems that Dairy Breed Societies, which have shown close attention to fat improvement in their merit schemes—with great success—can still continue to raise their fat standards without endangering their prime interest in still higher milk yields.

Summary

Milk recording has developed in recent years from the practice of a few pioneer cattle breeders to a movement covering a quarter of our dairy cattle. Through the Bureau of Records, the use of milk records has extended far beyond the individual herd owner, to all breeders and their organizations and to all those interested in cattle-breeding problems. Now, for the first time, information is readily available and the problems of the industry can be viewed, discussed, and analysed. Research can be directed to promising projects and can be based on full data.

There has been immense progress in performance. Yield has shown a continued increase and the fat content of the milk from each breed (especially Friesians) is higher than pre-war. The national average yield is now nearing 100 gallons per cow above pre-war and 170 gallons more that the lowest figure of the wartime period (Fig. 4).

While the factors contributing to this improvement in performance are many and varied and cannot readily be measured, a notable part has been played by the simultaneous expansion of the recording and breeding movements, which has stimulated interest in the breeding and management of dairy cattle. The specialist breeders and commercial milk producers are brought closely together in their nation-wide organizations, and close co-operation is established with research authorities.

The industry is now on the threshold of new developments, particularly on the breeding side as a result of advanced A.I. techniques. The three main organizations responsible are working together, backed by an efficient information service. Whatever the benefit forthcoming, the ultimate benefactor will be the breeder and herd owner, who at the very beginning, with great magnanimity, made possible past and future progress by allowing the records of his own herd to be available to others, a first-class example of agricultural co-operation in the best sense of the term.

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(Copies of publications Nos. 3–19 can be obtained on request from the Bureau of Records, Milk Marketing Board, Thames Ditton, Surrey.)

(*Received 23 September 1953*)

THE CONTROL OF *STOEBE VULGARIS* BY MEANS OF SELECTIVE WEEDKILLERS

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THE problem of Stoebe encroachment in the Highveld grassland regions of South Africa has been described by the author in a previous paper [1]. This woody perennial grows to a height of about 2½ ft. and develops a gnarled, thickened rootstock capable of regeneration after fire, trampling, mowing, &c. Flowering occurs in the autumn months and during winter the plant enters a dormant stage. In a heavily infested pasture as many as 50,000 plants per acre may be present.

Methods of control have been studied for the past twenty years at Frankenwald Field Research Station, Witwatersrand University, Johannesburg, and all the previous work may be summed up by stating that until selective weedkillers were investigated no satisfactory control measure had been found.

Investigational

Past work.—In 1948 experiments were begun at Frankenwald to study the effectiveness of selective weedkillers of the growth-regulating type in the control of Stoebe. Altona [2] reported the results of two seasons' spraying with the sodium salt of 2,4-D ('Fernoxone') and the sodium salt of MCPA ('Agroxone'). Spring treatment with the sodium salts gave significantly better results than treatment in summer and autumn, two treatments with MCPA at 2 lb. per acre giving a 53 per cent. kill.

Object of present investigation.—In 1950 the more active ester formulations of 2,4-D and 2,4,5-T became available and several comprehensive experiments were begun, with the following objects in view:

1. Comparison of the ethyl ester of 2,4-D with a mixture of the butoxy ethanol esters of 2,4-D and 2,4,5-T in the proportion:—one-third 2,4,5-T to two-thirds 2,4-D.
2. Comparison of water and diesel C.I. fuel as a carrier for the weedkiller.
3. Determination of the best season of application for these weedkillers.
4. Evaluation of the effect of various veld management practices on the effectiveness of the weedkillers. These management practices divided the investigation into five separate series, as follows:

(*a*) *No veld management*, with the application of herbicides in spring, summer, and autumn.
(*b*) *Winter burn*, with application in spring, summer, and autumn.
(*c*) *Midsummer mow*, followed by autumn application.
(*d*) *Autumn mow*, followed by spring application.
(*e*) *Autumn mow plus midsummer mow*, with application in autumn.

[Empire Journ. of Exper. Agric., Vol. 22, No. 85, 1954.]

The object of the winter burn was to remove the old, dry stems and so to allow complete wetting of the young shoots. It was thought that mowing in the growing season would remove the old vegetation and, in addition, deplete root reserves, thus making the plant more susceptible to the action of the weedkiller.

No-management and Winter-burn Series

Experimental.—Replicated, randomized plots $\frac{1}{20}$ acre in extent were laid out on a heavily infested old fallow in March 1950. Paths 3 ft. wide separated the plots. The total number of Stoebe plants in each plot was counted before treatment, and herbicides were applied by a pneumatic knapsack sprayer at a constant rate of 2 lb. acid-equivalent per acre, using 60 gallons water and 10 gallons oil per acre. Spring treatments were applied on 7 and 8 November 1950, summer treatments on 24 and 25 January 1951, and autumn treatments on 4 April 1951.

The treatments applied were:

1. 2,4-D in oil and in water in spring, summer, and autumn.
2. 2,4-D/2,4,5-T mixture in oil and in water in spring, summer, and autumn.
3. Oil alone in spring, summer, and autumn.
4. Control.

Observations.—Within 24 hours the Stoebe stem tips began to show epinasty, and within a week they assumed a yellow appearance, eventually turning a purple colour. After 4 weeks certain plants began to recover, and after 2 months this was quite noticeable. The main feature noted was that the spring-treated plants in both series did not increase greatly in size, and a rapid recovery of the grass population was possible in these plots.

The controls and the 2,4-D/2,4,5-T oil in spring plots were quadrated at the end of the 1952 season, giving the results shown in Table 1.

TABLE 1. *Basal Cover as per cent. of Total Area*

	Control plots	*2,4-D/2,4,5-T oil in spring*
	%	%
Stoebe vulgaris	7·60	1·12
Eragrostis chalcantha	1·00	2·20
E. brazoides	0·87	2·90
E. gummiflua	1·70	3·02
Total	11·17	9·24
Total grass	3·57	8·12

The grass cover more than doubled itself within one season, which indicates the strong competition between Stoebe and the grass species. This important factor of rapid grass recovery and the great reduction in

size and vigour of the Stoebe following herbicidal treatment is not reflected in the data on percentage kills, where a quantum response is obtained. Although Stoebe may still be present in treated plots, improvement in the grass sward is considerably more impressive than the percentage kill figures indicate.

The general trend of the effects of the summer treatments was similar to that of the spring application, except that all summer treatments incorporating the herbicide inhibited flowering completely—which the spring treatments did not accomplish. Seed production was therefore eliminated. The plants began to recover by the end of March but entered the dormant season in a much weakened condition, whereas the spring plots had sufficient time to rebuild reserves, and therefore entered the winter in a better condition than the summer-treated plants.

The increase in the grass population was not as spectacular in the summer plots as in the spring plots but by the following season a large number of grass seedlings had established themselves.

The autumn treatments were applied after flowering had taken place, and the effect on the plants was not marked.

Results.—The number of plants in each plot was re-counted twelve months after the first spring application and thus after all the treatments had been through one dormant season, allowing time for all possible reshooting after treatment. The percentage plants remaining in each plot was calculated and the results in Table 2 represent the averages of four replications per treatment.

TABLE 2. *Plants Alive after Treatment, as per cent. of the Number Originally Present*

Season of application	*Management*	*Weedkiller*					
		2,4-D oil	*2,4-D water*	*2,4-D/ 2,4,5-T oil*	*2,4-D/ 2,4,5-T water*	*Oil alone*	*Control*
		%	%	%	%	%	%
Spring	None	53·5	79·0	60·2	68·0	99·5	104·5
	Winter burn	46·0	64·7	46·2	76·7	89·7	105·7
Summer	None	45·4	44·7	52·2	55·0	97·0	..
	Winter burn	34·5	32·3	40·2	47·2	102·0	..
Autumn	None	79·2	79·0	71·7	86·4	96·9	..
	Winter burn	75·2	77·7	70·7	80·2	104·7	..

Least sig. diff. for no management = 16·5 per cent.; for winter burn = 22·7 per cent.

The significance of the effects of the various treatments and their interactions is shown in Table 3.

Discussion.—1. *Effect of winter burn.* Comparison of the sums of squares for the various treatments and their interactions shows that the two experiments yielded substantially similar results, and it may be inferred that the burn in winter made little difference to the weedkiller effects.

TABLE 3. *Analysis of Variance, Plants Alive after Treatment*

Source of variation	No management			Winter burn		
	D.F.	M.S.	F value	D.F.	M.S.	F value
Control *v.* remainder	1	4,026·2	16·6†	1	5,955	23·0†
Weedkillers:						
(*a*) Oil *v.* water	1	808·5	5·9*	1	1,452	5·6*
(*b*) Extra effect of 2,4,5-T	1	58·5	n.s.	1	320	n.s.
(*c*) (Oil *v.* water) × effect of 2,4,5-T	1	0·021	n.s.	1	261	n.s.
(*d*) Oil alone *v.* remainder	1	10,547	76†	1	16,269	62·9†
Seasons	2	2,806·6	20·3†	2	4,672	18·4†
Weedkiller × seasons						
(*a*) (Oil *v.* water) × seasons	2	254·7	n.s.	2	570	n.s.
(*b*) Extra effect of 2,4,5-T × seasons	2	133·0	n.s.	2	132	n.s.
(*c*) (Oil *v.* water × 2,4,5-T) × seasons	2	274·5	n.s.	2	6	n.s.
(*d*) (Oil alone *v.* remainder) × seasons	2	717·25	5·2*	2	1,196	4·6*
Error	48	137·5	..	48	258·6	..

* Sig. at P = 0·05. † Sig. at P = 0·01.

2. *Effect of weedkiller treatments.* The following conclusions can be drawn for both series:

(*a*) Taken over all seasons, oil proved to be superior to water as a carrier for the herbicide, whether this was 2,4-D or the 2,4-D/2,4,5-T mixture. However, although the (oil *v.* water) × seasons interaction was non-significant, there was a tendency for the gain through the use of oil in summer to be negligible.

(*b*) 2,4-D ester alone proved to be as effective as the 2,4-D/2,4,5-T mixture in reducing Stoebe infestation. This was so at all seasons and was not influenced by the carrier used.

(*c*) Oil alone appeared to be unsatisfactory as a weedkiller.

(*d*) The difference between oil alone and the weedkillers varied from season to season, the greatest difference being in summer. This was due not to a variation in the oil treatment but to the great improvement of all the weedkillers in summer. Summer, therefore, appears to be the best time to apply the weedkiller.

Mowing-herbicidal Treatment Series

It is essential to exhaust the reserve food supplies of a perennial plant if its eradication is to be achieved. Reduction in root reserves of grass following mowing of the tops was shown by Weinmann [3, 4], and Wort [5] showed that plant-growth regulators cause a reduction in the reserve carbohydrates of buckwheat. The mowing-herbicidal treatment series of

experiments was based on the hypothesis that the combination of mowing and herbicidal treatment would be more effective in eradicating Stoebe than would herbicidal treatment alone, as the result of a greater depletion of the root reserves.

Effect of 2,4-D/2,4,5-T on Stoebe root reserves.—A brief study was made of the total available carbohydrate status of Stoebe roots following treatment of the tops with the 2,4-D/2,4,5-T mixture already described, at the rate of 2 lb. acid-equivalent per acre. Diesel oil and water were used as carriers, applications being made in midsummer and autumn. Four replications were sprayed for each treatment and sampling took place one month after treatment. The method of analysis used was that described by Weinmann [6] with the modifications of Lindahl, Davis, and Shepherd [7]. Estimation of reducing sugars was made according to the Luff method.

TABLE 4. *Effect of 2,4-D/2,4,5-T on Total Available Carbohydrates in Stoebe Roots*

	Summer treatment		*Autumn treatment*	
	T.A.C. in sample	*Decrease*	*T.A.C. in sample*	*Decrease*
	%	%	%	%
Control . . .	12·25	..	14·81	..
Herbicide in water .	10·13	13·8	12·92	12·8
Herbicide in oil .	7·01	42·8	13·34	10·0

The greater effectiveness of summer applications over autumn applications and of an oil carrier as compared with a water carrier is borne out by these analyses and confirms field observations.

Experimental.—A pasture heavily infested with Stoebe was mown short in January 1951 for the midsummer mow and herbicides were applied in March 1951 (autumn). Another portion was mown in March 1951 for the autumn mow and herbicides applied in late November 1951 (spring); and a further portion of infested pasture was mown in March 1951, again in January 1952 (double mow), and herbicides applied in March 1952.

In each of the above series the following treatments were applied in randomized blocks with four replications.

1. 2,4-D ethyl ester in oil, in water, and in an oil/water emulsion carrier.
2. 2,4-D/2,4,5-T ester in oil, in water, and in an oil/water emulsion carrier.
3. Oil alone.
4. Control.

The weedkillers were applied as in the previous experiments—namely at 2 lb. acid-equivalent per acre.

The emulsion carrier consisted of 10 per cent. diesel oil in water and was sprayed at the rate of 60 gallons per acre. Sufficient emulsifiers were present in the weedkillers to emulsify this quantity of oil.

Results.—All treatments were allowed a year for possible reshooting,

at the end of which period all the remaining plants were re-counted. The percentage plants alive for each of the mowing series are given in Table 5, as averages of four replications.

TABLE 5. *Plants Alive after Treatment, as per cent. of the Number Originally Present.*

Weedkiller	*Midsummer mow*	*Autumn mow*	*Autumn mow plus midsummer mow*
	%	%	%
2,4-D oil	31·0	40·5	21·0
2,4-D water	55·5	55·2	39·7
2,4-D emulsion	22·0	26·5	12·2
2,4-D/2,4,5-T oil	30·5	35·2	25·0
2,4-D/2,4,5-T water	30·2	48·2	32·2
2,4-D/2,4,5-T emulsion	26·7	29·5	12·0
Oil alone	92·2	82·2	73·2
Control	100·0	86·5	83·7
Total	388·1	403·8	299·0

For purposes of statistical analysis the percentage values were transformed to the appropriate angles; Table 6 gives the total values for each treatment, and Table 7 shows the significance of effects and interactions.

TABLE 6. *Angular Values Summed, Plants Alive after Treatment*

Treatment	*Midsummer mow*	*Autumn mow*	*Autumn mow plus midsummer mow*
2,4-D oil	132·8	158·4	105·6
2,4-D water	192·7	194·4	155·6
2,4-D emulsion	111·9	121·4	80·3
2,4-D/2,4,5-T oil	132·1	145·2	119·1
2,4-D/2,4,5-T water	131·1	176·0	137·1
2,4-D/2,4,5-T emulsion	124·0	131·5	77·5
Oil alone	305·2	272·7	237·7
Control	360·0	287·5	281·2
Total	1,489·8	1,487·1	1,194·1
L.S.D.	36·49	51·56	54·51

TABLE 7. *Analysis of Variance, Plants Alive after Treatment*

Source of variation	*Midsummer mow*			*Autumn mow*		*Autumn mow plus midsummer mow*	
	D.F.	*M.S.*	*F*	*M.S.*	*F*	*M.S.*	*F*
(Control+oil) *v.* remainder	1	14,283·76	374†	5,917·33	77·03†	8,094·19	94·2†
Control *v.* oil	1	375·38	9·7†	27·38	n.s.	236·53	n.s.
Effect of 2,4,5-T	1	105·00	n.s.	19·26	n.s.	2·53	n.s.
Carriers	2	250·76	6·52†	434·14	5·65*	568·70	6·62†
Interaction	2	193·84	5·03*	28·79	n.s.	32·00	n.s.
Error	21	38·45	..	76·82	..	85·89	..

* Sig. at P = 0·05. † Sig. at P = 0·01.

Discussion.—1. *Effect of mowing.*—(*a*) Comparison of the figures for 'percentage plants alive after treatment' in Table 2 with those in Table 5 shows that mowing increased the susceptibility of the plants to herbicidal treatment.

(*b*) The influence of season of mowing can be seen in Tables 5 and 6. They show that a trend existed in favour of the double mowing, and this was very clearly demonstrated in a field examination of the plots, the remaining Stoebe plants in the double-mow treatment being small and weak. There appeared, however, to be little difference between the midsummer and autumn mowings.

2. *Effect of weedkiller treatments.*—(*a*) A very highly significant difference existed between the weedkillers and the average of 'control and oil alone'. No difference was shown between the control and the oil alone, except in the midsummer-mow experiment, where there appeared to be a highly significant effect. In 'no-management' and 'winter-burn' experiments no significant difference was found between oil alone and control, and it is thought that the result from the 'midsummer-mow' experiment was fortuitous despite its statistical significance.

(*b*) Highly significant differences existed between carriers. In the 'midsummer-mow' experiment both oil and emulsion were superior to water, but in the 'autumn-mow' and 'double-mow' experiments the superiority of oil over water disappeared leaving only the emulsion superior to water.

(*c*) On the other hand, when 2,4,5-T was added no significant difference appeared to exist between carriers in the 'midsummer-mow' and the 'autumn-mow' experiments. In the 'double-mow' experiment, however, the superiority of the emulsion over water remained whether 2,4,5-T was present or not.

(*d*) On the average the effect of adding 2,4,5-T to the 2,4-D fell short of significance, except (as in (*c*) above) where 2,4,5-T added to 2,4-D improved the effect with the water carrier.

Aerial Spraying

The results from the detailed experiments proved so encouraging that it was decided to broaden the scope of the work by undertaking experimental aerial applications of 2,4-D ester in diesel oil. A midsummer application at the rate of 1 lb. acid-equivalent was made in 2½ gallons diesel oil per acre to Stoebe burnt in the previous winter and to unburnt Stoebe. In the following autumn the area was again treated at the same rate. The treatment allowed such rapid grass recovery that within two months new grass was pushing its way through the large Stoebe bushes, which were unable to compete successfully with the grass.

The application in autumn of 2 lb. acid-equivalent of 2,4-D ester in 2½ gallons diesel oil per acre to Stoebe mowed in midsummer has given excellent results, and can be recommended as a practical method of field eradication.

Discussion on All Experiments

The effect of the winter burn on the susceptibility of the plant appeared to be negligible. This was presumably due to the fact that

destruction of the tops during the dormant season affects the root reserves but little. The decided disadvantage of a winter burn from the point of view of control was, however, very evident from aerial spraying experiments on Stoebe where 2½ gallons of oil and weedkiller were applied per acre. Burnt bushes produced shoots of approximately 6 in. in height by the following summer, while the unburnt bushes stood at 2½–3 ft. in height. The effect of the aerial application was far greater on the unburnt bushes than on the burnt, presumably because the unburnt bush offered a larger surface to absorb and translocate the small quantity of toxic solution that was applied.

Mowing during the actual growing season appears to have accomplished the desired effect in making the plant more susceptible to the herbicide. The effect of the double mowing was such that it might be possible to reduce the quantity of herbicide applied to 1 lb. per acre and still achieve a reasonable kill. In all cases, however, a single spraying is not sufficient to eradicate all the plants, a further spraying being necessary. Where this has been given at the rate of 1 lb. per acre almost complete eradication of Stoebe has been effected.

The effect of 2,4-D/2,4,5-T in diesel oil on the production of natural climax grassland was studied and it was found that rates up to 5 lb. acid-equivalent per acre in 10 gallons oil per acre did not interfere with final grass production. A slight scorching of the grass occurred but this soon disappeared.

The effect of the oil in the oil-alone and emulsion treatments is thought to be due to improved wetting and penetration into the plant, and the greater effectiveness of oil and emulsions over water as a carrier is in agreement with the work of Gertsch [8].

Evidence as to the effect of 2,4,5-T when water was used as a carrier was conflicting, and a more detailed experiment would be necessary to settle this point.

The effectiveness of the ester formulation of 2,4-D appeared to be far greater than that of the sodium salt of 2,4-D and MCPA when used against Stoebe. Moreover, the best season for the application of the sodium salt was found [2] to be the spring. This, however, may have been due to the particular conditions of the year during which the application was made, or to an interaction between the season and the formulation of herbicide.

Summary and Conclusions

1. No satisfactory method of eradicating *Stoebe vulgaris* from pastures had been found until the advent of the synthetic plant growth regulators.

2. Experiments are described in which the application of herbicides in various carriers was made to Stoebe, (*a*) in spring, summer, and autumn following no cultural management; (*b*) in spring, summer, and autumn following a burn in winter; (*c*) in autumn following a mowing treatment in midsummer; (*d*) in spring following a mowing in autumn; (*e*) in autumn following a mowing in autumn followed by a mowing in midsummer.

3. Where relatively high-volume applications of weedkillers (10 gallons per acre and upwards) were made, the winter burn did not materially influence the results. If, however, very low-volume applications were made, as in aerial spraying, burning in winter was decidedly disadvantageous.

4. Mowing the tops during the growing season, and particularly a double mowing, improved the effectiveness of the herbicides, presumably by lowering the carbohydrate reserves in the plant. 2,4-D/2,4,5-T applied in oil to Stoebe tops was shown to cause a reduction in total carbohydrates present in the root.

5. Where no mowing took place summer appeared to be the most effective time for herbicide application, but if mowing was done the herbicides might be applied at any season with equal effectiveness.

6. On the average the effect of adding 2,4,5-T to 2,4-D fell short of significance, leaving 2,4-D ester to be chosen as a suitable herbicide for Stoebe control.

7. In the 'no-mowing' experiments and in the 'midsummer-mow' experiment oil was superior to water as a carrier for the herbicide, and in all three mowing experiments an emulsion was superior to water.

Acknowledgements.—The writer wishes to acknowledge a grant from the University of the Witwatersrand which enabled the work to be initiated. Professor N. P. Badenhuizen, Department of Botany at this University, assisted with the carbohydrate determinations, and Professor A. A. Rayner, of Natal Agricultural Research Institute, Pietermaritzburg, kindly assisted with the statistical analyses.

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(*Received 3 August 1953*)

POTATO BLIGHT IN WEST AFRICA

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THE Irish potato (*Solanum tuberosum* L.), though not widely grown in West Africa, is planted in a few areas of elevated land. The widest of these is the highlands of Bamenda, which form part of the trust territory of the Cameroons administered by the United Kingdom, and the adjoining land about Dschang under trusteeship of France. Potatoes, probably brought here during the German occupancy of the territory before 1915, have since been adopted by the native tribes as an important part of their diet.

In this country, about 6 degrees north of the equator, potatoes are found mostly above 6,000 ft. in small tilled patches carved out of the prevailing grassland. The shifting cultivation here practised is of a most primitive type. All the work is done by women of the tribe, their only tools a hand-hoe and a stout knife. In the area to be planted, the grass is burned at the onset of the dry season about the end of November and the surface soil is scraped up into raised beds or barrows of varying size, but commonly about 6 by 4 ft. In this loose soil the potatoes which have been saved for seed are planted with the first rains in March, and seed of other crops, such as maize and kidney bean, is often interplanted. The first crop of potatoes is taken in July and a second crop, planted in late August, is harvested in December.

Occurrence of disease.—Until recently, observers have commented on the apparent freedom of Cameroons potatoes from serious disease. In May 1952, however, there came a report of the destruction of the first crop by a disease which, starting near the French boundary, swept across Bamenda Province. A description of the symptoms suggested that this was blight due to *Phytophthora infestans*. In a visit made in November 1952, at the time of the second crop, the presence of this fungus was confirmed in every plot of potatoes examined throughout the area. In 1953 the first crop was again attacked, though rather less severely than in the previous year. The fungus was also found on leaves of tomato.

Potato blight is almost as widespread as the potato itself, and Distribution Map No. 109 of the Commonwealth Mycological Institute shows that *P. infestans* is present in most countries in the tropics as well as in temperate lands. In Tropical Africa it was recorded by Nattrass [1] as appearing in Kenya in 1941, by Wallace [2] in Tanganyika in 1942, and it was identified from the Belgian Congo and Uganda by Hendrickx [3] in 1943. There has been no published record of its occurrence on the west coast of Africa and the outbreak here described represents an extension of the disease into a new area. The identity of the fungus as *P. infestans* (Mont.) de Bary has been confirmed at the Commonwealth Mycological Institute.

[Empire Journ. of Exper. Agric., Vol. 22, No. 85, 1954.]

One can only conjecture whence it may have come. Two points of possible significance arose in conversation with the Chief Agricultural Officer in the adjoining French territory; the first, that the disease appeared in the French part of the Cameroons in 1951, a year earlier than it was noticed on the British side; the second, that eating potatoes have been imported from France and, on occasion, some of these have been planted. In these circumstances blight may readily have been brought from Europe.

Means of control.—To an impoverished people dependent for their existence on what they can scrape from the soil, the loss of a staple crop is serious. It is considered likely that the disease will recur each year, for infection now occurs throughout the area and climatic conditions (which as in most parts of the tropics follow a regular pattern each year) could hardly be better suited to the fungus. The first crop is subject throughout its life to heavy rainfall and to temperatures ranging from 50° to 75° F. Gram and Weber [4] point out that the fungus is most destructive under such conditions of heavy rain and moderate temperature, the fungus growing rapidly on the leaves at 68–77° F., the sporangia forming best at 66–72° F., and the swarm-spores being most active at 52–55° F. The second crop is planted under similar conditions, but about two months after planting the rainfall declines, the day temperature rises above 80° F., and with the resultant fall in humidity the disease is checked. This, however, may happen too late to save the crop.

Control by fungicides, though effective elsewhere, appears to have little application at present in the Cameroons where the people are too backward to do the work effectively themselves, and where the potato plots are too small and scattered for action by a co-operative or central authority to be practicable. Moreover, it is not clear that fungicidal spraying can here be economically done. Bordeaux mixture at 1 per cent. strength, applied to potatoes on Government farms at 10-day intervals throughout the period of growth, failed to prevent destruction of the crop from blight. It seems likely that, in the prevailing conditions of heavy rainfall and temperatures favourable to the fungus, much more frequent applications would be necessary.

The use of blight-resistant varieties may offer a brighter prospect of success. In East Africa potato seedlings supplied by the Scottish Society for Research in Plant Breeding [5] have shown immunity to blight, and Nattrass [6] describes their commercial production in Kenya. A later report from Kenya [7], however, mentions the breakdown of some of these on the arrival of a new strain of the fungus from Tanganyika. As Black [8] and others have pointed out, there are several strains of the fungus, so that the choice of a potato variety to show resistance must be related to the strain or strains which it will meet. Black himself has isolated nine specialized strains in addition to strain A, the common cause of blight. Varieties resistant to the common strain have been developed and are in commercial use in several countries, including the United States, Canada, India, and Germany.

Trial of resistant varieties.—Since it was not known what strain of the fungus might be in the Cameroons, Dr. Black kindly supplied a small

collection of seedlings resistant to a range of strains. At the same time several blight-resistant varieties were sought from the United States Department of Agriculture and the Dominion Horticulturist, Canada. These were planted at the Government Farm, Bambui, in March and April 1953, within a field of the local susceptible variety. By mid-June the field was completely blighted with the exception of most of the introduced varieties which remained green and vigorous. Their reaction to blight attack is shown in the Table.

Reaction of Potato Varieties to Blight Attack at Bambui

(*a*)	(*b*)	(*c*)	(*d*)	(*e*)
		Highly resistant		
Seedling 1521*c* (3)	Cherokee	Placid	Canso	..
1521*d* (24)	Kennebec	..	Keswick	..
1522*c* (11)	Pungo	..	..	..
1564*a* (14)	B 73–10	..	..	..
1565 (4)	B 73–18	..	..	..
1664*a* (12)	B 922–6	..	..	..
1668*b* (7)	..	..	..	..
1928*e* (2)	..	..	..	..
		Slightly resistant		
	B 922–3	..	..	..
		Susceptible		
	..	Chenango	..	Smooth Skin

(*a*) From Scottish Plant-Breeding Station.
(*b*) From USDA, Beltsville, Md.
(*c*) From Cornell University, N.Y.
(*d*) From Dominion Horticulturist, Ottawa.
(*e*) Local.

It is of interest to find so many of these varieties retaining their resistance to blight in the Cameroons. I am indebted to Dr. Black for the opinion that, while similar results might be obtained from other strains, it seems most likely that it is the common strain of *Phytophthora infestans* which is now present in West Africa.

Summary.—Potatoes are cultivated on the highlands of Bamenda Province, Cameroons, and have become an important food of the people. In 1952 the crop was devastated by a disease identified as blight due to *Phytophthora infestans* (Mont.) de Bary, a fungus which is believed not previously to have been recorded in West Africa.

In a preliminary trial, blight-resistant potato varieties introduced from Scotland, United States, and Canada gave promising results.

Acknowledgements.—The assistance of those who so kindly sent potato varieties for testing, and of Mr. I. G. Mathers of the Nigerian Department of Agriculture, who supervised the trial at Bambui, is gratefully acknowledged. The author is obliged to the Inspector-General of Agriculture, Nigeria, for permission to publish this account.

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(*Received 23 November 1953*)

FIELD RESPONSES BY KENYA COFFEE TO FERTILIZERS, MANURES, AND MULCHES

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THE Kenya coffee plantation industry incurs heavy annual expenditure on cattle manure and on phosphatic fertilizers in the belief that such dressings are essential for high coffee yields. This belief was, however, developed without the evidence of adequate field experiments. The present paper reports the results of a number of years of field experiments, accompanied by soil and plant analyses, relating to the use of nitrogenous and phosphatic fertilizers, cattle manure, and grass mulches with coffee in Kenya.

Soils and climate.—The main coffee-producing areas of Kenya are located on closely similar soil types, named by Gethin Jones [1] the Kikuyu series. These are very deep, friable, red lateritic 'loams' derived by Pluvial Era leaching from porous lavas and tuffs. They are the most fertile soils of the Kenya Highlands and extend for some 5,000 square miles. Coffee plantations are also successful on the newer lava-derived chocolate loams of Mount Elgon, on small areas of alluvially reassorted volcanic ash, and on sandy soils derived from the metamorphic rocks of the Archaean 'Basement Complex'. The failure of other plantations over wide areas has served to define the physical soil requirements of *Arabica* coffee, which are those of free drainage and good aeration to a minimum depth of 5 ft. and to an optimum depth in excess of 12 ft.

The climatic requirements are satisfied between 4,500 ft. and 6,800 ft. above sea level, being limited either by drought or by leaf disease at the lower altitude and by temperature at the higher altitude. The Kenya coffee plantations lie within approximately 100 miles north and 100 miles south of the Equator, and receive rainfalls of between 30 and 60 in. per annum. The rainfall distribution is usually unfavourable, the rain being concentrated into either one or two intensive wet seasons, with intervening hot dry periods of great severity.

Root range of coffee.—The root system of *Coffea arabica* in East Africa has been studied by Nutman [2], Trench and Beckley [3], and Rayner [4]. The main characteristics are a dense surface root mat, filling the first 2 ft. of well-aerated top-soil, and a system of deep vertical roots extending 12 ft. or more in depth. The root system is strongly affected by over-cultivation and loss by erosion of the topsoil, and also by the death of deep roots from starch exhaustion caused by overcropping.

Nutrient requirements of Kenya coffee.—Analyses over many years have established fairly consistent nutrient levels in the main coffee soils of

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[Empire Journ. of Exper. Agric., Vol. 22, No. 85, 1954.]

volcanic origin. These are well supplied with potash, low in total phosphate, and extremely low in both the water-soluble and citric-soluble phosphate fractions. Nitrogen levels fluctuate widely with seasonal rainfall, and are often very low. Soils of the Basement Complex may be low in potash also [5, 6]. By analogy with crops and soils of the temperate zones, increased crop yields were expected from dressings of phosphates, cattle manure, compost, and, in years of high rainfall, from nitrogenous fertilizers. Such dressings have been advised in the past and are still widely practised throughout the industry.

Observations of the responses of a tree crop to treatment are particularly difficult for the practical grower to make. Coffee yields are strongly affected by seasonal variations in rainfall and in temperature, by cultural policies of pruning and weed control, and particularly by seasonal over-cropping and biennial bearing. Where yield responses have appeared to be disappointing, the fertilizers and manures have frequently been said to improve ripening or quality of crop. The quality of the coffee is itself complicated by varying techniques of picking, factory fermentation, washing and drying. It is not surprising, therefore, to find that opinions among experienced coffee planters on the subject of fertilizers and manures are unusually conflicting.

Evidence from field trials.—Before 1944, when the Government acquired the 300-acre Jacaranda coffee estate at Ruiru, facilities had not been available in Kenya for field trials on a scale adequate to overcome the variability of the crop. The field evidence existing at that time has been collected from unpublished records in Departmental files and field-books, and is presented below. Table 1 summarizes five early trials in which, although the designs did not provide for an adequate estimate of error, there was sufficient replication to permit a useful estimate of the order and direction of the apparent response on different soil types.

A further series of small observation plots was begun by Burton in 1937 on a number of private plantations. This scheme was disrupted by the outbreak of war and the few yields obtained were too variable to contribute useful evidence. Two small experiments of valid design were subsequently conducted at substations and the results are summarized in Table 2.

None of these records supported the general expectation of large responses to phosphates and to cattle manure, although they appeared to confirm a lack of response to potash and to lime. They suggested that nitrogen fertilizers required closer investigation, and that the phosphate applications current in the coffee industry might well be unprofitable.

Modern Field Experiments

Experiments of modern factorial design were therefore set out on the new Coffee Research Station at Ruiru, designed to establish with confidence the smallest responses of economic importance. Plot size and replication were decided after analysis of individual tree records available from earlier Departmental seed selection work. In the first experiment, four balanced replications of a $3 \times 3 \times 3$ design were employed [7]. The

TABLE 1 *Early Field Evidence for Responses of Coffee to Fertilizers and Manures*

A. Experimental Conditions

Experiment No.	*Place and year of experiment*	*Altitude in feet*	*Annual rainfall in.*	*Soil type*	*Plot size in acres*	*No. of plots*	*No. of years*
1	Kasirini Estate, Kiambu (1925–6)	5,500	35	Volcanic red lateritic 'loam'	$\frac{1}{5}$	46	2
2	Scott Agricultural Laboratories, Kabete (1934–45)	5,700	37	ditto	$\frac{1}{11}$	9	11
3	Ona Estate, Solai (1929–31)	6,000	42	Alluvially assorted volcanic ash	$\frac{1}{4}$	13	3
4	Rongai Estate, Elgon (1938–44)	6,500	50	Chocolate volcanic lateritic 'loam'	$\frac{1}{4}$	9	7
5	Teldet Estate, Elgon (1935–40)	6,800	50	ditto	$\frac{1}{7}$	21	5

B. Treatments and Responses

Experiment No.	*Annual treatments per acre*				*Apparent response (as % of control)*				
	N *lb.*	P *lb.* P_2O_5	K *lb.* K_2O	*Cattle manure tons*	N	P	K	*Cattle manure*	*Green manure*
1	30	35	28	..	+16·7	−2·3	−5·4	..	−11·6
2	50	88	20	6	+47	−6	−13	+16	..
3	25	80	40	7	+ 8·7	+4·9	+0·6	+ 2·9	..
4	..	66	..	4	..	+4·2	..	+15	+ 3·5
5	40	80	75	6	+ 0·1	+1·0	−1·4	+ 1·4	− 8·8

C. Effects of Other Treatments

1. Lime at $\frac{1}{2}$ ton per acre gave +10 per cent. response in the first year but had severely adverse effects in subsequent years.
2. No significant effects on quality in 11 years.
3. NPK fertilizer, +7·4 per cent.
4. Grass mulch, +67·4 per cent.
5. Lime, −20·5 per cent.

D. Sources of Data

1. V. A. Beckley. Unpublished data from Departmental files.
2. Department of Agriculture, Coffee Services, unpublished records.
3. A. D. le P. Trench. Unpublished data from Departmental files.
4. R. O. Reynolds. Private estate records.
5. J. F. Perkins. Private estate records.

TABLE 2. *Substation Experiments on Cattle Manure and Phosphates*

Location of experiment	*Altitude and annual rainfall*	*Coffee culture and soil type*	*Design of experiment*	*No. of years*	*Annual treatments and responses (per cent.)*		
					Phosphates	*Cattle manure*	*Green manure*
Karamani Substation, Thika (1938–43)	5,100 ft. 33 in.	Single stem unshaded. Red volcanic lateritic 'loam'	4 randomized blocks	6	400 lb./acre bonemeal −2·4%	7 tons/acre +4·5%	..
Agric. Exper. Station, Kitale (1944–9)	6,200 ft. 46 in.	Multistem mixed shade. Red sandy loam from gneiss and schist.	5 × 5 Latin square	5	400 lb./acre Seychelles guano +2·6%	5 tons/acre +3·2%	Lupins laid as mulch +6·0%

None of the responses reached the 5 per cent. level of significance

degree of replication proved effective in that the 5-year yield totals, quoted below, had a least significant difference (at $P = 0{\cdot}05$), of only 6 per cent. of the mean yield.

The experiment was situated on level ground on a broad ridge typical of Kenya's main coffee-producing areas. The trees were of the genetically heterogeneous 'French Mission' type, and were about 30 years old. The spacing was 10 × 10 ft. (435 per acre). They had all been stumped in 1945 to secure uniformity. The top-soil was in fair structural condition, showing no severe signs of past erosion. Rayner [4] excavated root systems of sample trees and found them to reach depths of about 12 ft.

Bonemeal, previously believed to be the form of phosphate least likely to revert to unavailable forms in the soil, had been in short supply since 1946. At the same time, East African sources of rock phosphate were being developed, and information was required both on Uganda rock phosphate and on the soda-phosphate locally manufactured from it. These forms were therefore used in the trials. The annual treatments were:

Nitrogen: 0, 1, and 2 cwt. sulphate of ammonia per acre.
Phosphate: 0, 45, and 90 lb. P_2O_5 per acre (containing 0, 7, and 3½ lb. citric-soluble P_2O_5 per acre) given as 0, 2 cwt. soda-phosphate, and 3¼ cwt. Uganda rock phosphate respectively.
Cattle manure: 0, 3½, and 7 tons per acre, given as 0, 1, and 2 'debbies' (4-gallon tins) per tree.

These dressings represented once and twice the maximum annual applications used in current commercial practice. The dressings were hoed into the soil around each tree. Where phosphates and cattle manure were given to the same plots, the phosphates were incorporated into the manure several weeks before its application to the coffee.

Table 3 summarizes the yields for the first five years and incidentally emphasizes the dominant effect of annual rainfall. The yields reflect

also the steady growth of the trees between 1947 and 1951. Responses to treatments were slight even in years of good rainfall, and only nitrogen gave any promising signs of response. No effects of the manurial treatments on the quality of the crop could be detected.

TABLE 3. *Yields for Five Years, as cwt. Clean Coffee per Acre*

Crop year	Annual rainfall (in.)	Mean yield	Nitrogen			Phosphates			Cattle manure			Least sig. diff. $P = 0.05$
			N_0	N_1	N_2	P_0	P_1	P_2	C_0	C_1	C_2	
1947	52·42	5·46	5·53	5·32	5·52	5·46	5·40	5·51	5·51	5·47	5·40	0·26
1948	31·44	1·56	1·50	1·51	1·68	1·51	1·63	1·56	1·62	1·48	1·59	0·18
1949	25·51	2·05	2·05	1·89	2·20	2·01	1·88	2·26	2·07	2·05	2·03	0·49
1950	26·20	2·76	2·71	2·85	2·72	3·18	2·76	2·35	2·70	2·62	2·96	0·42
1951	54·05	10·93	10·37	11·12	11·30	10·83	10·84	11·13	11·39	11·00	10·41	0·84
5-year total yields			22·16	22·69	23·42	22·99	22·51	22·81	23·29	22·62	22·39	1·25

Effect of nitrogen.—The first hundredweight of sulphate of ammonia did not give a significant increase in any year, whilst the higher level increased yields in 2 years out of 5. These increases were not offset by biennial bearing, and the overall result, from five annual dressings, was a significant increase of 7 per cent., or 1¼ cwt. of clean coffee per acre. This covered the cost of materials and application, but was only moderately profitable. Indications from a subsequent experiment, reported below, suggest that considerably higher levels of nitrogenous fertilizer are required for Kenya coffee.

Effect of cattle manure.—The cattle manure did not increase yields, and in 1951, the year of heaviest rainfall, it appeared to cause a reduction in yield. The interaction (Table 4) with nitrogen in this year showed that the manure alone had no effect on crop yield. Two cwt. of sulphate of ammonia per acre, applied without manure, gave a significant increase in crop; this increase was completely eliminated by 7 tons of manure per acre.

TABLE 4. *1951 Yields, showing Interaction of Nitrogen and Cattle Manure*

(*As per cent. of control yield, 10·3 cwt. clean coffee per acre*)

	N_0	N_1	N_2
C_0	100	114	117
C_1	100	108	110
C_2	100	101	101

Least sig. diff. ($P = 0.05$), 13·9

The manure in 1951, contained 40 to 50 per cent. of water, and the dry matter contained between 2·2 and 2·5 per cent. of nitrogen. It was made on the estate by yarding cattle under cover at night on dry elephant-grass, and the manure was turned down a series of concrete hillside stages until ready for use. The finished product approximated to the F.Y.M. of temperate zone agriculture in physical consistency.

Effect of phosphates.—No yield responses were obtained from phosphates. The widespread belief that they accelerate ripening of the coffee was tested by plotting each season's pickings. No effect whatever was detected. Although this confirms the results of the earlier trials reported in Tables 1 and 2, and although many other tree crops have shown similar lack of response when phosphates are supplied to mature trees, the contradiction with current practice in the Kenya coffee industry was so great that the problem was further investigated. The rates of application of citric-soluble phosphate were low, and it seemed desirable to ascertain whether the kind of fertilizer and method of application had enabled the trees to obtain any of the added phosphate.

Phosphate uptake by coffee and weeds.—The phosphate content of foliage samples, determined both by ashing and by the extraction of fresh tissue, showed small effects of phosphatic fertilizers in the order sodaphosphate > rock phosphate > control, indicating some uptake from the fertilizers. In one sampling the sulphate of ammonia application had a greater apparent effect on the phosphate content of the foliage than did the phosphatic fertilizers. Measurements were made of the quantity of phosphates removed in the crop, and of the quantities mobilized by weeds during the rains. The total phosphate content of the cherries showed no effects of fertilizers and the average removal per hundredweight of clean coffee yield was 0·67 lb. P_2O_5. This indicates an average phosphate removal of only 3 to 4 lb. P_2O_5 per acre per year. In 1949 weeds were cut by a motor scythe from twenty-seven strips, each of 300 sq. ft. The main species were *Tagetes minuta*, *Bidens pilosa*, *Oxygonum atriplicifolium* and *Amaranthus* sp. Fertilizer treatments caused no significant differences in either fresh or dry weight or in total phosphate content, but cattle manure increased weed growth as shown in Table 5. Since these weeds are not removed, their content of phosphate is returned to the top-soil, and represents about four or five times as much phosphate as is removed annually in the coffee crop.

TABLE 5. *Effect of Cattle Manure on Weed Growth and Uptake of Phosphate*

	Manure applied, tons per acre			*Least sig. diff.* $P = 0{\cdot}05$
	0	*3½*	*7*	
Fresh weight of weeds, tons/acre . .	5·0	5·3	6·2	0·95
Oven dry weight of weeds, tons/acre .	1·37	1·48	1·76	0·28
P_2O_5 content of weeds, lb./acre . . .	15·6	16·6	18·7	2·4

Phosphate status of soils of coffee field trials.—An examination of the phosphate status of the soils throughout the first 10 ft. of the root range was made by digging pits in the guard rows of three control plots on each of five of the coffee field trials described above. Birch [8] examined these soils and his results are summarized in Table 6.

TABLE 6. *Phosphate Status of Untreated Soils of Coffee Fertilizer Trials*

($A = P_2O_5$ *in p.p.m. extracted by* N/10 HCl
$B = P_2O_5$ *in p.p.m. extracted by* N/10 HCl + N/2 NH_4F)

Location mean annual rainfall (in.)	*Thika* 33			*Ruiru* 35			*Kabete* 37			*Kitale* 46			*Elgon* 50		
Soil type	*Kikuyu red 'loam' (a lateritic clay soil)*									*Red sandy loam*			*Chocolate 'loam' (lateritic clay)*		
Parent material	*Nairobi trachyte (massive sheet lava)*									*Basement complex gneiss and schist*			*Recent lava*		
Laboratory measurements	*pH*	*A*	*B*	*pH*	*A*	*B*	*pH*	*A*	*B*	*pH*	*A*	*B*	*pH*	*A*	*B*
Top-soil, 0–1 ft.	5·9	10	84	6·0	20	147	5·6	4	122	5·7	15	156	6·5	101	572
Sub-soil at 2 ft.	5·9	0	0	6·1	1	21	5·4	0	0	6·2	2	35	6·0	5	180
,, at 4 ft.	6·6	0	0	6·2	0	16	5·8	0	0	6·3	4	34	5·6	4	133
,, at 6 ft.	5·2	0	2	6·0	0	18	6·0	0	2	6·4	1	39	5·5	3	133
,, at 8 ft.	5·4	0	39	5·8	0	8	5·1	0	30	6·8	4	70	5·1	2	152
,, at 10 ft.	..	..	(Murram)	5·5	0	12	6·1	0	21	6·9	2	57	..	..	..

A high concentration of phosphate in the surface soil was a common feature of the three soil types, and it was not due to manuring because the Kabete, Kitale, Elgon sites had not previously received fertilizers. The zero values for so effective an extractant as an acid solution of ammonium fluoride, on subsoil of 65 to 80 per cent. clay content, demonstrate the very low original phosphate status of the Kikuyu Red Loam; these results also illustrate the necessity to base fertilizer recommendations on results of field trials rather than on chemical analyses. Microplot tests using cereal seedlings have been suggested for diagnosis of coffee manurial requirements, but in recent valid field trials on all three soil types cereals have shown significant positive responses to phosphates, e.g. wheat and maize at Kitale and maize on Mount Elgon [9], and green maize for silage at Ruiru [10].

Effects of heavier applications of fertilizers and manure.—In 1950 a subsidiary experiment, testing heavier dressings of nitrogen, phosphates, and cattle manure, was begun at Ruiru on trees adjoining those of the one already described. Staff considerations precluded a large experiment, and two replications of a $2 \times 2 \times 2$ design were used. Although the assessment of clean coffee was made more accurate by sampling all pickings of all plots, the eight effective replications proved inadequate, and standard errors were inconveniently high. Treatment details and results for the first three seasons are given in Table 7.

Over the first 3 years, cattle manure used at four times the usual rates failed to increase yields. Sulphate of ammonia continued to give erratic positive responses, but three annual applications of 4 cwt. per acre produced a total response of approximately $6\frac{1}{3}$ cwt. of clean coffee. At the price of £400 per ton then prevailing, this represented an increase

in profit of over £100 per acre in 3 years. Phosphate, as double superphosphate, in an annual dressing containing about 100 lb. of citric-soluble P_2O_5 per acre, showed no beneficial effect, and in the first year caused an apparent reduction in yield.

TABLE 7. *Responses to Heavier Applications of Manure and Fertilizers*

(as per cent. of control yields)

Treatment		*Sulphate of ammonia 4 cwt./acre*	*Double super. 2 cwt./acre*	*Cattle manure 14 tons/acre (4 × ins/tree)*		
Control yields cwt. clean coffee/acre		*Mean resp. to* N	*Mean resp. to* P	*Mean resp. to* C	*Least sig. diff.* $P = 0.05$	$P = 0.01$
1950	3·6	+52·1†	−17·4	− 3·2	26·6	39·3
1951	4·2	+ 1·7	− 4·9	−15·3	40·9	60·5
1952	15·0	+32·1†	− 3·0	+ 9·8	21·5	31·8
3-year totals	22·8	+28·7†	− 5·2	+ 2·8	9·0	13·0

† sig. at P = 0·01. No other responses reached significance at $P = 0.05$

Effects of manuring on the carbohydrate balance of the trees.—Defoliation with subsequent die-back of crop-bearing branches is believed to be due to starch deficiency, and is a normal symptom during and after a heavy yield [3, 11, 12]. It is controlled by seasonal variation in the severity of pruning, which prevents the bearing of excessive crops. In the field experiments described in this paper, the pruning was standardized as far as possible to permit heavy cropping, and thus to avoid the imposition of an arbitrary limit on yield responses. The considerable incidence of dieback which resulted provided a supplementary estimate, in conjunction with crop yields, of the effects of the treatments on the starch balance of the trees. All died-back branches were therefore counted annually on all trees in the Ruiru experiments. Dead branches were subsequently removed by pruning. In the 5 years of the experiment described in Table 3, the manurial treatments significantly affected dieback only in the first year, 1947, when 2 cwt. of sulphate of ammonia reduced dieback by 17 per cent. In the supplementary experiment the 4 cwt. of sulphate of ammonia gave a significant reduction in each year and in the 3-year totals (Table 8), whilst phosphate and cattle manure

TABLE 8. *Effects of Treatments on Number of Died-Back Branches per Tree*

	Sulphate of ammonia 4 cwt./acre		*Double super. 2 cwt./acre*		*Cattle manure 14 tons/acre*		*Least sig. diff.* $P = 0.05$	$P = 0.01$
	No N	N	No P	P	No C	C		
1950	10·7	7·8	9·3	9·3	10·6	8·0	1·9	2·9
1951	48·5	33·4	42·1	39·8	42·4	39·5	10·4	15·3
1952	15·6	8·6	13·1	11·2	13·7	10·6	3·9	5·8
3-year totals	74·8	49·8	64·5	60·3	66·7	58·1	13·5	20·0

had no significant effect. Both the crop yield and the condition of the trees were thus improved by the sulphate of ammonia.

Effects of manure from native cattle bomas.—In addition to the testing of specially prepared cattle manure as described above, a concurrent experiment has given substantial evidence concerning the effectiveness of the standard commercial practice of applying cattle manure bought from native cattle bomas in the dry plains.

An extensive cultivation and weed-control experiment begun in 1947 has eighty-one plots, covering some 16 acres in all, split for application of dry boma manure from the Athi Plains [13]. This has been given, as in commercial practice, at one 4-gallon tin per tree per year (about 3½ tons per acre). Over 4 years, this material has not produced a yield increase under any of the wide range of cultivation and weed-growth conditions under which it has been tested. The total yields for 4 years were:

With boma manure	83,572 lb. cherry
No manure	82,238 „ „
Apparent response	1·62 per cent.
Least significant difference . .	3·31 „ „

Analyses were made from numerous samplings of the manure applied, and showed wide variations in the proportions of water and soil in the material as purchased, e.g. from 12 to 30 per cent. of water and from 45 to 75 per cent. of earth. Of the oven-dry matter as little as 15 per cent. might be oxidizable organic matter. The dry matter contained about 2 per cent. of nitrogen. The very low values for loss on ignition published for Uganda kraal manure [14] suggest that this may be a common feature of cattle manure from native sources in East Africa.

The Effects of Grass Mulches

In contrast to the lack of return from fertilizers and manures, there was (as Table 3 shows) a striking response to variations in the total annual rainfall. Neither rivers nor underground water resources are, in general, adequate for irrigation of coffee in Kenya, although experiments (1942–9) on *Arabica* coffee at the Lyamungu Coffee Research Station in Tanganyika have shown responses to irrigation under an average annual rainfall of over 60 in. Much, however, can be done to make best use of the limited rainfall in Kenya coffee areas by grass mulching the coffee, as described by Gilbert [15]. The practice was formerly advocated in Kenya as an alternative measure pending the production of adequate supplies of cattle manure [16]. The experimental evidence before 1950, for the relative merits of grass mulches and of cattle manure as methods of applying organic matter to Kenya coffee plantations, has been reviewed by the present authors [17].

Times of application of grass mulches.—Studies of soil moisture changes in fallow plots, testing different thicknesses and times of application of grass mulches, were carried out by a combination of soil sampling and of electrical resistance techniques [18, 19]. (A full account of these

measurements will be published separately.) Little difference was observed between elephant grass, maize stover, and sorghum stalks, for all of which a minimum practical application consisted of sufficient loose material to settle, in the field, within 3–4 weeks, to a depth of 4 in. The initial depth depends on the nature and condition of the loose material, and may be from 5 in. to 9 in. or more.

In the soil moisture studies the best time of application was found to be before the rains, as opposed to the usual practice on those estates using mulching, which was to cut, at the end of the 'long rains' of April to June, the grass grown during these rains, and to apply it to the coffee after the final weeding [16]. In Kenya (east of the Rift Valley) the moisture conservation effects of grass mulches are due primarily to the greater depth to which rainfall penetrates under the favourable surface conditions secured by the mulching. This effect is quantitively greater than that of subsequent protection of the soil surface from drying out.

To increase coffee yields, therefore, the most efficient technique of mulching should be to cut and to apply the grass during dry weather preceding the rains, so that maximum soil protection is provided at the onset of the rains. This was put to a full-scale field test in 1950. Two replicates of a 2^5 design included quantity and time of application of grass mulching, together with both cattle manure and nitrogen treatments [20]. The initial results gave striking confirmation of the hypothesis about time of application, the effects being sufficiently large and consistent, both in a year of extreme drought and in a year of heavy rainfall, to be quoted with confidence in spite of the present short duration of the trial. Table 9 gives the yields for these first 2 years. The multistem coffee then reached the end of its cycle and although treatments have continued, the 1952 season was occupied by conversion to new stems, and the crop was negligible.

TABLE 9. *Coffee Yields, showing Response to Grass Mulches*

(*Cwt. clean coffee per acre*)

Year	*Total rainfall (in.)*	*Control: no mulch*	*Mulched before long rains: all rows*	*Mulched before long rains: alternate rows*	*Mulched after long rains: all rows*	*Least sig. diff.* $P = 0.05$	$P = 0.01$
1950	24	0·76	1·52	1·09	0·71	0·33	0·44
1951	54	6·81	12·08	10·58	9·82	1·14	1·53

In both wet and dry years, one-half the quantity of mulching grass, applied in March before the 'long rains', gave yield increases greater than were obtained from the full quantity applied at the customary time in June.

Cattle manure was included in this experiment to observe possible effects in the favourable environment provided by the mulch. As Table 10 shows, there was no interaction, the manure remaining ineffective in spite of the protection provided by the most favourable mulching treatment.

TABLE 10. *Coffee Yields: Interaction of Cattle Manure and All-row Mulch*

(*Cwt. clean coffee per acre*)

Year	*Rainfall total (in.)*	*Control*	*Manure*	*All-row mulch before rains*	*Mulch and manure*	*Least sig. diff.* $P = 0.05$	$P = 0.01$
1950	24	0·61	0·91	1·49	1·54	0·47	0·62
1951	54	6·67	6·95	12·30	11·86	1·60	2·16

Nitrogen treatments were included both to observe possible interactions with mulching and to establish a range of soil conditions for nitrogen studies. Many more seasons will be required to elucidate these interactions, but in the wet conditions of 1951 there were significant negative interactions between nitrogen fertilizers and the pre-rains mulches, sulphate of ammonia having the greatest depressing effect

TABLE 11. *Coffee Yields: Interaction of Nitrogen Fertilizers with Mulching in 1951*

(*Cwt. clean coffee per acre*)

		Nitrogen at 23 lb. per acre given as		
	No nitrogen	*1 cwt. sulph. of ammonia*	*1·29 cwt. nitrate of soda*	*1·32 cwt. 'nitro-chalk'*
No mulch . . .	5·22	7·38	8·19	6·45
All-row pre-rains mulch	13·45	9·63	12·73	12·50

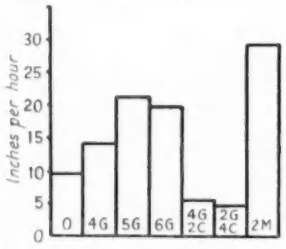
Least sig. diff., $P = 0.05$, 2·25 cwt.
$P = 0.01$, 3·11 cwt.

(Table 11). A similar depressing effect of sulphate of ammonia on the yield of mulched coffee has been reported, under wetter conditions, from Tanganyika [21].

These results raise points of particular importance for advisory work. Firstly, they do not support any suggestion that grass mulches create a need for an increased use of nitrogenous fertilizers. Secondly, they pose the problem of securing simultaneously the maximum responses from both nitrogen and mulching treatments. The obvious practical compromise is to broadcast the nitrogen fertilizer on the strips of soil not covered by the mulch. The latter normally covers only 7 ft. of the 10-ft.-wide lane between the trees, a space being left in order to avoid possible waterlogging effects during heavy rains. Where limited grass supplies permit only alternate row mulching, nitrogen fertilizers should be applied in the unmulched rows.

Effects of grass mulches on soil structure.—Rapid improvements in soil structure by grass mulches have been measured in the Ruiru field trials. These changes have been briefly described elsewhere [22]. On a uniform slope the top-soil had deteriorated during 30 years of coffee cultivation, leaving 3 in. of red dust over hard subsoil. The coffee was condemned

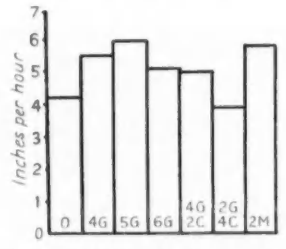
by an experienced officer to be uprooted and replaced for several years by elephant grass in order to restore soil structure before replanting. This was done in 3-acre plots, while part of the area was used for a mulch trial in which the original soil conditions were maintained on the control plots. In 1951 seven contrasting conditions of the first 3 in. of soil were examined by a number of physical techniques. The results



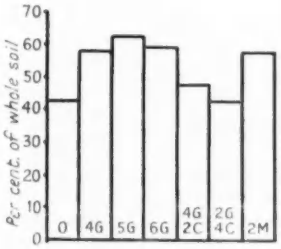
(*a*) Percolation through soil cores under 1 cm. constant head of water.

Key to Treatments

O. Original conditions, after 30 years of coffee cultivation.
4G. After 4 years' rest under elephant grass.
5G. After 5 years' rest under elephant grass.
6G. After 6 years' rest under elephant grass (in this area cultivation had been necessary to remove 'couch' grass).
4G2C. 4 years of rest under grass and 2 years of coffee cultivation.
2G4C. 2 years of rest under grass and 4 years of coffee cultivation.
2M. All-row grass mulch for 2 years (mulch was removed before tests were made).



(*b*) Percolation through soil cores under artificial rainfall at 6 in. per hour.



(*c*) Water-stable aggregates over ¼ mm. diameter.

FIG. 1. Soil structure improvement under a grass mulch

are summarized in Figure 1. The very rapid improvement in the physical condition of the soil under a grass mulch, and the transient nature of the improvements affected by the roots of elephant grass, are both points of practical importance to the planter.

Field problems of grass mulching.—Three major difficulties are the supply of very large quantities of grass for extensive coffee plantations, the supply of labour for the current primitive methods of hand application, and the control of weeds among partly decomposed mulch residues. On all of these further research is needed. Although the mulches might appear to be inflammable in the dry season, experience has shown that the danger is negligible.

The quantities of grass required have been estimated by extensive sampling of field experiment mulch applications, and the quantities of nitrogen and phosphorus in the material have also been determined (Table 12). The amounts vary greatly according to the effect of the season on the growth of the elephant grass (*Pennisetum purpureum*) used in these trials.

Table 12 emphasizes the need to sun-dry the material thoroughly before handling, and suggests the need to replace the nutrient elements in soil which is producing a succession of heavy mulch-grass crops. Used on the mulch-grass area of the coffee plantation, fertilizers may eventually give indirect increases in coffee yields. Experiments to determine fertilizer effects on mulch grasses are in progress.

TABLE 12. *Weight per Acre of Grass Mulch Applied*

(*Mulch 7 ft. wide and 4 in. deep in all rows of a 10 × 10 ft. plantation*)

Year	*Time of application*	*Weight of wilted grass (tons)*	*Oven-dry weight of grass (tons)*	*Weight of ash (tons)*	N *content (lb.)*	P_2O_5 *content (lb.)*
1949	July: after rains	27	10·0	1·37	88	60
1950	May: after rains	45	11·2	1·83	220	150
1951	March: before rains	37·7	9·3	1·58	152	108
1951	June: after rains	23·3	5·3	0·81	143	73

Wide variations in weight are due to different proportions of leaf and cane-like stem. Density of elephant grass stems and their age when cut depend on the variations in seasonal rainfall.

The control of weeds in heavily mulched coffee is difficult with mechanical cultivation, since the protective trash must be kept on top of the soil. The use of weed-controlling sprays is an obvious possibility, and in preliminary experiments testing methods recommended from Puerto Rico [23], sprays of furnace-oil emulsions containing pentachlorphenol gave useful control of some weeds without apparent damage to coffee. Stoloniferous grasses, particularly *Digitaria abyssinica*, on the other hand, were not effectively controlled. Applications of trichloracetate sprays have been tested, but concentrations high enough to control such 'couch' grasses have also caused severe damage to the coffee trees [24]. Couch grasses are, however, at present eradicated by hand and present no difficult problems on well-tended estates.

The mechanical handling of grasses in bulk has been the subject of a great deal of research and development in other fields of agriculture, but these methods have not yet been applied to mulch grasses in coffee plantations. Some of the more promising lines of development for Kenya conditions have been discussed by Pereira [25].

Further research work directed to the growing and the mechanical handling of bulky mulch grasses, and the control of weeds in mulched coffee, should lead to substantial increases in the yields of Kenya's coffee plantations.

Summary

Field experiments on coffee in Kenya showed that, over the range of conditions in whicht he bulk of this colony's coffee is produced, neither yield nor quality of the crop was affected by the usual dressings or by

heavier dressings of either cattle manure or phosphates. Crop yields were sometimes increased when nitrogenous fertilizers were given at heavy rates.

Coffee yields depend greatly on annual rainfall. Soil moisture measurements showed that important additional conservation of water could be achieved by applying grass mulches before the rains to improve reception rather than by the customary applications after the rains to prevent evaporation. Field trials confirmed this by large yield increases when a mulch was applied before the rains. Soil structure was greatly improved under grass mulches. Organic matter should therefore be applied directly in coffee plantations as surface protection rather than be converted to manure and dug in. The nutrients supplied in grass mulches are considerable and exceed those removed annually in the coffee crop. They should be made good in the soil which produces the grass.

Acknowledgements.—Thanks are due to Mr. A. R. Melville, Senior Research Officer (Coffee), and to Mr. R. W. Rayner (Plant Pathologist and Physiologist) for advice and encouragement, and to the field and laboratory staff of the Coffee Research Station for their assistance in the investigations described.

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(*Received 11 June 1953*)

MONTH OF CALVING, AGE AT FIRST CALVING, AND CALVING INTERVALS OF THE BUFFALOES IN A DAIRY HERD IN EGYPT

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LIVESTOCK rearing in Egypt is comparatively neglected owing to the importance of the cotton crop, and the farmers are poor stockmen. In 1949 the total population of buffaloes in the country was estimated at $1\frac{1}{4}$ million head [1]. Buffaloes possess many commercial advantages such as longevity and resistance against tuberculosis; they are also hardy and can consume coarse feeds. The males are usually slaughtered at about 2 months of age, and the females are mainly kept for milk production, or sometimes they work in the fields. The average body weight of the female and male buffalo at birth was found to be about 38 and 41 kg. respectively [2]. The average weight of the males at maturity was 725 kg. whereas that of the females was 640 kg.

There are two main types of buffalo in the country, the names adopted for them referring to geographical regions. The Beheri type in Lower Egypt, in the north, is heavier and covered with fine hair over the face, neck, and shoulders. The Saidi type in Upper Egypt, in the south, is smaller in size with coarse, black, shining hair which is not uniform in its distribution over the body. (Khishin [3] classified the buffaloes in Egypt into four distinct types, but three of these, in Lower Egypt, showed only minor differences.) The different appearances of the two main types may be attributed to differences in environment. The average monthly temperature during 1952 was about 21·1° C. in the north and about 23·1° C. in the south, and the corresponding average rainfall was 70·5 and 20·0 mm. respectively. Most of the rainfall in the north is received on the coast during winter [4].

The present investigation was undertaken primarily in order to obtain information about the month and the seasonal nature of calving. It also showed the effect of age at first calving on yield in the first lactation and on the first calving interval (cf. [3]). In the commercial herd studied, no mating season was arranged and animals calving reared a calf for about 30 days, after which they were milked twice daily. This herd was founded in 1928 near Alexandria.

The data collected covered the period between 1928 and 1951. The number of recorded animals was 315 buffaloes, with 1,370 calvings. The size of the herd during the period was about 1,000 animals.

Results and Discussion

Month of calving.—The number of animals that calved in different months of the year and their average ages in terms of number of calvings are set out in Table 1.

[Empire Journ. of Exper. Agric., Vol. 22, No. 85, 1954.]

It will be seen that the buffalo cows calve throughout the year, and that a high proportion of animals calved between September and March. This could be attributed to the feeding of the buffalo on berseem (*Trifolium alexandrinum*) from December to June each year, which would have raised the rate of fertile services for the animals bred at that time. The atmospheric conditions may also have had a bearing on the low conception rate between July and November. However, seasonal trends in

TABLE 1. *Number of Animals calving in each Month, and their Average Number of Lactations*

Month of calving	*No. of animals*	*Per cent. of total no.*	*Mean age in lactations*
January . .	152	11·09	3·53
February . .	151	11·02	3·21
March . .	148	10·80	3·35
April . . .	91	6·64	2·91
May . . .	73	5·33	2·98
June . . .	50	3·65	4·10
July . . .	66	4·82	3·69
August . .	83	6·06	3·19
September .	127	9·27	3·45
October . .	126	9·20	3·26
November . .	143	10·44	3·23
December . .	160	11·68	3·90
Total or mean .	1,370	100·00	3·39

fertility-level for buffaloes have also been reported by previous authors [5]. The buffalo cows that calved in April and May in the present study tended to have the lowest age, whereas those calving in June were the oldest.

The average age of the buffalo cows recorded here was 3·39 lactations. This figure underestimates the age of the herd because old animals that were introduced into the herd during the period studied were not included in the calculations owing to their unknown history. Further, the length of productive herd life of the buffalo is expected to be longer than the above figure suggests, because some of the animals studied will be kept for more lactations. The average working life of the buffalo in a herd was shown by the author [6] to be five lactations, although the estimate reported by Kishin [3] was only 3·78.

The effect of month of calving on production was obtained by dividing the lactation records into twelve groups according to the month of calving. These records were not corrected for age as this did not have any significant effect on production. The results obtained are given in Table 2.

There were some differences between the average milk yields of animals calving in different months of the year. The buffalo cows that calved between December and April tended to have higher yields. Therefore it is probable that berseem feeding has a favourable effect on the development of the inherent capacity of the buffalo cows to produce milk. Certain other factors such as the environmental conditions may also influence production.

Age at first calving.—The average age of 221 animals at their first calving was 39·4±0·67 months, compared to 33·8 months for European cattle [7]. The corresponding figure obtained by Kishin [3] was 38 months. Evidence based on present work on the Alexandria University herd suggests that buffalo heifers could be bred successfully at about

TABLE 2. *Relationship between Month of Calving and Milk Production*

Month of calving	*Total no. of animals*	*Milk yield gallons*	*Relative yield %*
January	112	370·0	100·0
February	103	383·7	103·7
March	115	393·6	106·4
April	77	383·2	103·5
May	58	345·4	93·3
June	35	362·3	97·9
July	62	355·2	96·0
August	51	355·2	96·0
September	95	371·3	100·3
October	99	353·3	95·5
November	97	361·0	97·6
December	123	375·8	101·5
Total or mean	1,027	370·1	100·0

2 years of age provided that they were kept from birth under good feeding conditions. The effect of age at first calving on milk yield in the first lactation was calculated; the regression value of −0·08 gals. obtained for an increase in age of 1 month was not significant. The calving intervals, which represent both the lactation periods and the dry periods, were calculated for the first lactations of buffalo heifers calving at different ages. The results obtained are given in Table 3.

TABLE 3. *Age at First Calving and the Corresponding First Calving Interval*

Age at first calving (months)	*First C.I. mean (days)*	*No. of animals*
20–24	686	7
25–29	740	9
30–34	646	45
35–39	681	57
40–44	708	41
45–49	707	24
50 and over	822	18
Mean or total	697	201

Buffalo heifers that calved at a later age tended to have longer calving intervals between their first two calvings, owing to the breeding difficulties that may have accompanied their first and second calvings.

Calving intervals and lactation periods.—The calving intervals, lactation periods, and dry periods for similar lactations of all the recorded animals in the herd were calculated and the results are set out in Table 4.

In the first lactation, the calving interval tended to be longer than the values obtained for the later lactations. Because the first calvers are still growing, they may need a longer resting period before they get in calf again. The values calculated for subsequent lactations were variable, and they were complicated by culling for yield, fertility, disease, &c. The dry periods for the different lactations followed much the same trend

TABLE 4. *Calving Intervals, Lactation Periods, and Dry Periods of All Recorded Members of the Herd, by Lactations*

(Mean number of days ± S.E.)

Lactation	*No. of animals*	*Calving interval*	*Lactation period*	*Dry period*
1 . .	201	697±18·4	361± 8·9	337±16·7
2 . .	163	632±20·9	356± 7·8	276±19·8
3 . .	108	655±27·1	363±10·9	292±23·7
4 . .	76	640±29·3	336±10·9	304±29·4
5 . .	40	543±36·6	322±11·4	220±35·2
6 . .	25	605±47·1	352±27·5	254±56·5
7 and over .	21	599±65·7	360±13·5	240±67·7
Total or mean .	634	650±25·6	354±10·2	296±24·6

as the calving intervals, whereas the lactation periods were not regular. The variability among the lactation periods in all lactations was less than that for the dry periods or the calving intervals. The standard error of the lactation periods amounted to 2·9 per cent. of its mean, whereas it was 8·3 per cent. for the dry periods and 3·9 per cent. for the calving intervals. Average values for calving interval, lactation period, and dry period previously reported [3] were 585, 362, and 231 days respectively. The calving interval and the dry period were shorter than those observed in the present investigation, whereas the lactation period agreed with that found here.

The average length of the calving interval for all lactations was rather high, and this was due to an increased service period (interval from calving to conception). The disadvantage of a longer calving interval is that it increases the intervals between generations and thereby tends to decrease the annual genetic gain.

The average length of the service period based on 120 records was 283±16 days. It has been pointed out that 'silent heat occurred in 38·71 per cent. of the total expected oestrous cycles' in buffalo cows [5]. Accordingly, animals to be bred should be controlled carefully for the most suitable time of serving in order to avoid a very long service interval. The question of the best length of service period for dairy buffaloes in Egypt was not included in this investigation.

The length of the calving interval or the service period was closely related to that of the dry period as was shown by correlation coefficients

of +0·91 and +0·86 respectively. A low negative correlation (−0·05) was found between the lactation period and the dry period. The coefficient calculated for the preceding dry period and the current service period was +0·08 and insignificant.

The extent to which the environmental factors may influence the characters studied was shown by calculating the repeatability [8]. The repeatability values obtained for the calving interval, the lactation period, and the dry period in successive records were 0·15, 0·16, and 0·18, based on 539, 752, and 517 lactation pairs respectively. Kishin [3] gave a value as high as 0·28 for the repeatability of the calving interval. Similar estimates reported by other investigators [9] were 0·05 for the calving interval and 0·26 for the lactation period. The fact that the calving intervals in the present data were long and showed a high variability may explain why our repeatability was higher than that found in [9]. In the case of the lactation period, the analysis in [9] was restricted to data from animals that had completed at least 200 days' lactation; this could be the reason for the higher estimate.

Although the number of recorded herds is limited, we believe that the present herd is above the average for the whole country. However, the results obtained show that it is necessary to adopt more suitable methods of management, since these tend to have a considerable effect on the performance of the animals. Moreover, selection of the local types may also be effective, and this would allow for further possibilities of improvement.

Summary.—Results are given of a long-term study of times of calving and related factors in a large commercial dairy herd of buffaloes, founded in 1928 near Alexandria.

The numbers of calves born in different months showed a clear seasonal trend, a larger proportion of the calves being born in winter than in summer. There were corresponding seasonal trends in the fertility-level and the capacity for milk production of the herd.

The average age of the buffalo cows at first calving was 39·4 months.

The average lengths of the calving interval, the lactation period, and the dry periods were 650, 354, and 296 days respectively; the repeatability estimates of the characters were 0·15, 0·16, and 0·18 in the same order.

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(Received 21 November 1953)

A SURVEY OF THE VALUE OF FERTILIZERS TO THE FOOD-FARMING AREAS OF THE GOLD COAST

PART III. THE VOLTAIAN SANDSTONE REGION AND THE SOUTHERN MAIZE AREAS

P. H. NYE

THE methods used in an extensive series of trials with sulphate of ammonia and superphosphate on peasant holdings were described in Part I of this series (this *Journal*, 1953, **21**, 176). In the present part the results of the survey on the Voltaian sandstone soils in the savannah will first be described, and then the results for the very different maize-growing areas of the south of the country.

The Voltaian sedimentary rocks, which cover the whole of the central portion of the country, consist predominantly of sandstone, conglomerates, shales, and mudstones. The soils developed over the shales and mudstones lie very wet during the rains, and on the upper and middle slopes there is only a very shallow depth of soil overlying iron pan. Dry-season water supplies are usually poor. Consequently, these soils, which represent more than half the Voltaian area, are practically unfarmed. The areas of conglomerate also are mainly low-lying and little used. All the important agricultural soils are developed over sandstone. The four areas surveyed—the Tamale, Yendi, Ejura, and Wenchi areas, totalling 4,760 sq. miles—cover the most densely populated sandstone soils in the savannah. There are also well-populated districts on the southern fringe of the Voltaian, but they are in forests, and except in the Krobo area (see below) the main interest is cocoa. Other less populated sandstone soils, for example in south Mamprussi, will almost certainly behave like the Tamale and Yendi areas in the Northern Territories, or the Ejura and Wenchi areas in northern Ashanti.

Area boundaries

Tamale. Latitudes 9° 40′ N. and 9° 20′ N., longitudes 0° 40′ W. and 1° 50′ W.
Yendi. Latitudes 9° 30′ N. and 8° 30′ N., longitudes 0° 10′ E. and 0° 10′ W. Also an isolated area around Karaga: Latitudes 10° 0′ N. and 9° 50′ N., longitudes 0° 20′ W. and 0° 30′ W.
Ejura. Obosum sandstone area between Ejura and Atebubu.
Wenchi. Latitudes 7° 40′ N. and 8° 30′ N., longitudes 2° 8′ W. and 1° 40′ W.

Although the experimental results for the four areas have been grouped, certain differences between the soils, climate, and agriculture make it necessary to give brief separate descriptions of the Tamale and Yendi, the Ejura, and the Wenchi areas.

Tamale and Yendi Areas

Soils.—The farmed soils in these two areas are underlain by Lower Voltaian medium- or fine-grained sandstone, except around Tamale

[Empire Journ. of Exper. Agric., Vol. 22, No. 85, 1954.]

town, where there is a small outlier of coarse Upper Voltaian sandstone. The dry-farm soil consists of loose, fine- or medium-sandy, brown topsoil liable to cap when dry, with an increasing amount of clay at depth. It is usual to strike ferruginous gravel or pan at between 6 in. and 36 in. The topography is gently undulating. The upper-slope soils are usually too shallow to farm, most of the farming being done on the middle- and lower-slope soils above the seasonal flood level in the valleys.

Climate.—The average annual rainfall at Tamale is 43 in. and at Yendi 52 in. The rainy season extends from early April to late October, and is thus spread over a rather longer period than in the far north, which enables maize and yams to be grown. The dry season is hot and the humidity low. The rainfall of the 1950 season is compared with the average in Table 1.

TABLE 1. *Rainfall Data for Selected Stations in the Voltaian Sandstone Areas*

Month	TAMALE				YENDI			
	Year 1950		Average		Year 1950		Average	
	in.	Rain days	in.	Rain days	in.	Rain days	in.	Rain days
Jan.	0·00	0	0·06	1	0·38	1	0·19	1
Feb.	0·00	0	0·25	1	0·13	2	0·28	1
Mar.	0·03	1	2·13	4	0·11	1	1·70	3
Apr.	1·20	4	3·26	6	2·12	6	3·75	5
May	3·29	11	4·69	9	3·93	9	5·18	7
June	4·30	7	5·52	11	3·77	9	5·57	9
July	5·30	13	5·47	12	3·25	11	6·04	9
Aug.	2·62	9	8·24	14	5·39	12	8·09	12
Sept.	5·72	14	8·82	18	5·92	17	11·11	15
Oct.	3·65	13	3·63	10	5·76	8	5·08	10
Nov.	0·00	0	0·65	2	0·00	0	0·71	2
Dec.	0·31	1	0·17	1	0·36	1	0·35	1
Annual total	26·42	73	42·89 (40 years)	89	31·12	77	48·05 (28 years)	75
	WENCHI				EJURA			
Jan.	0·07	1	0·23	1	2·23	3	0·55	1
Feb.	0·20	2	1·77	3	0·19	2	2·07	3
Mar.	1·88	6	3·44	6	4·09	4	4·45	7
Apr.	6·00	9	5·66	8	4·71	6	5·84	9
May	6·50	16	6·67	9	7·05	9	7·88	12
June	5·52	14	8·21	12	5·50	12	8·19	14
July	1·31	5	3·43	7	2·37	8	4·28	8
Aug.	2·21	7	2·73	6	4·09	5	3·00	7
Sept.	4·95	17	7·59	13	4·50	11	8·39	14
Oct.	11·92	22	8·53	16	11·90	19	8·71	16
Nov.	1·70	4	2·96	6	1·24	6	3·87	8
Dec.	0·00	0	0·77	1	2·12	3	0·85	2
Annual total	42·26	103	51·99 (28 years)	88	49·99	88	58·08 (34 years)	101

Agriculture.—The farming of the Tamale area has been described by Akenhead [1]. No agricultural survey of the Yendi area has been made, but it does not appear to differ in any important respects from the Tamale area.

In contrast to North Mamprussi, and in common with all the remaining areas to be described, shifting cultivation is practised everywhere, the people living in villages. The land is cropped for about 3 years. The resting period ranges from about 2 years in the immediate neighbourhood of the villages, and for some distance around big centres such as Tamale and Yendi, to 10 years and upwards. The fallow consists of grasses, notably *Andropogon gayanus*, about 6 ft. high, as well as shoots from stumps, and scattered trees that have been preserved. It is burned every dry season. Practically no use is made of kraal manure.

The land is almost invariably opened with yams (*Dioscorea* sp.). The earth is hoed into mounds about 2 ft. high, and the yams are planted directly, either at the end of the year before the soil is too dry or at the beginning of the next rains; the harvest ranges from July to November depending on the time of planting and the variety of yam. Late millet (*Pennisetum* sp.) or, in the wetter area, rice is sometimes planted between the mounds. In the second year, as soon as the rains become fairly reliable in April, a quick-growing maize is planted, usually with guinea corn (*Sorghum* sp.) though sometimes with late millet. The maize matures early in August before the heaviest rains, and the other cereals in November or December. The position of maize is thus closely analogous to early millet in the far north. The third year's cropping is variable. Late millet is usually grown, sometimes alone, or mixed with another cereal or a legume such as groundnuts.

The crops selected as most likely to respond profitably to fertilizers were yams and mixed maize and guinea corn. In the Tamale area there were also trials on groundnuts.

The Ejura Area

The area lies along the north road between the Pru and the Sene rivers, on the Obosum sandstone. The land with the same geology to the south-east lying within the bend of the Sene, is too wet for cultivation. There remains a fairly well-populated area between Atebubu and Basa to which results from the Ejura area should apply.

Soils.—The Obosum sandstone is a medium-grained felspathic sandstone. On the upper and middle slopes of the undulating terrain the soils consist of brown or orange-brown medium-sandy top-soils. There is an increasing amount of clay in the subsoils, and ferruginous gravel or pan usually lies within 2 to 4 ft. though it may approach nearer the surface. On the lower slopes along the margins of the seasonally-flooded valleys there are deep colluvial sands, wet during the rains, suitable for upland rice.

Climate.—The average rainfall at Ejura is 58 in. It has the double-peak distribution characteristic of the south, commencing in March with maximum fall in June and September, and ending in November. Two quick-growing crops are thus possible in one year.

Agriculture.—The area is relatively sparsely populated, the fallow period, following about 3 years' cropping, being rarely less than 5 years and usually more than 10. Yams are the opening crop, maize on the drier or rice on the wetter areas being planted between the mounds. In the second year, on the drier areas maize or to a lesser extent groundnuts is planted in the first season and the same crops are usually planted for the second season. On the wetter areas upland rice is planted in June and harvested in November–December. In the third year, cropping is very variable but as a rule cassava is planted and the land left to return to fallow, the cassava being harvested in small quantities as it is needed after about a year's growth.

Yams and rice were selected as the crops most likely to profit from fertilizers.

The Wenchi Area

Soils.—The area overlies the upper Voltaian coarse-grained massive sandstone, which rings the southern rim of the Voltaian basin. The topography is steep and the upper-slope soils are usually shallow. On the middle and lower slopes the top-soils are orange or reddish-brown coarse-sandy loams, and there is an increasing proportion of clay at depth; concretionary gravel or pan is not conspicuous in the root zone, and the valleys are not seriously flooded. If it were not for the steepness of the terrain these soils would be the most suitable for development in the whole of the Voltaian savannah.

Climate and agriculture.—The climate is very similar to that in the Ejura area, and the farming pattern is similar to that on drier soils of the same area.

Yams and maize were selected for trial. Unfortunately the maize was badly attacked by rust which reduced yields to one-quarter of the average.

Experimental Results

The mean yields of the crops under trial in the Voltaian sandstone region, responses to the fertilizers, and their linear interactions are summarized in Table 2, and a discussion of them follows. The results for the maize at Wenchi are not included, but the marks accorded to the growing crop before the rust attack developed indicate effects similar to those with maize at Tamale and Yendi, where the cobs were well developed before the rust spread seriously.

Main effects: Nitrogen.—There were moderate responses to sulphate of ammonia on cereals. With yams, the response to the double dressing was just 10 per cent. of the untreated mean, which was disappointing since this is the main cash crop of the region. Rice was under trial in the Ejura area only, and a large number of trials was spoilt by premature harvesting by farmers; from the successful trials it appeared that there were moderate responses, but the error was too high for a very reliable estimate.

Phosphorus.—There was a significant, though small, response to the double dressing of superphosphate with cereals. With yams and rice

the response was not appreciable. Groundnuts are not a major crop in this region and were under trial in the Tamale area only, where their response to superphosphate was relatively high, though much of this was probably due to the calcium-sulphate content of the superphosphate which stimulates this plant in nitrogen-deficient soils [2, 3], an effect now attributed to sulphur [4].

TABLE 2. *Voltaian Sandstone Areas. Responses to Single (60 lb. per acre) and Double (120 lb. per acre) Dressings of Sulphate of Ammonia and Superphosphate, and their Linear Interactions*

N_1, P_1 are responses to single dressings;
N_2, P_2 are responses to double dressings
(*lb. per acre*)

Crop	*No. of sites*	*Responses and linear interaction*							*Mean yield*	*S.E.*
		N_1	N_2	*S.E.* (N_2)	P_1	P_2	*S.E.* (P_2)	$N_2 \times P_2$		
Mixed crop:										
Maize	39	51	92	..	41	89	..	40	498	..
Guinea corn	..	185	220	..	47	109	..	−16	894	..
		236	312	63	88	198	69	24	1,392	120
Yams . .	80	253	527	153	−55	144	149	−149	5,528	268
Groundnuts (Tamale area only) .	24	Not applied			101	202	54	..	532	84
Rice (paddy) (Ejura area only) . .	8	242	111	109	36	43	53	−32	1,350	265

Linear interactions.—The linear interaction between nitrogen and phosphorus fertilizers was not appreciable with any of the crops.

Correlation of response with the cropping history of the sites.—Previous work at experimental stations had indicated that in this region the responses to fertilizers were correlated with the cropping history of the sites. Land cleared after a long grass fallow was very short of available nitrogen in the first year. On sites more frequently cropped there was a fair level of available nitrogen in the early part of the season, but it was deficient in the latter part. Only small responses to phosphorus were obtained on land long fallowed, and moderate responses when the fallow was shorter. Accordingly in these experiments a division has been made between 'little-cropped' sites with more fallow than cropping in the last 10 years, and 'much-cropped' sites with as much or more cropping than fallow. The 'little-cropped' sites include some 'long-fallow' sites which had not been cropped for 10 years or more. The percentage responses and mean yields obtained when the sites are classified in this way are shown in Table 3.

Both the nitrogen and phosphorus responses with cereals and yams tended to be greater on the much-cropped sites, though the differences were not significant. This indicates that in this region, where there is not severe pressure on the land, the farmers leave the land to fallow before serious shortages of nutrients develop.

The failure of yams to respond well to nitrogen on the long-fallow sites is interesting. Yams are nearly always taken as the first crop after the fallow has been burnt. An acute shortage of nitrogen in these conditions has been found with cereals, and it was notable that there were no examples in these trials of farmers planting cereals as the first crop on a long-fallow site. The relative response to nitrogen of yams is much less than that of cereals, and if there were real differences in response between the long-fallow sites and the remainder, the error was too great to detect them in this series of trials. The relative insensitivity of yams to

TABLE 3. *Variation in Fertilizer Responses with Cropping History*

Crop	*Sites*	*No.*	*Responses (per cent.)*						*Mean yield (lb. per acre)*
			N_1	N_2	*S.E.* (N_2)	P_1	P_2	*S.E.* (P_2)	
Yams . . .	Much-cropped	20	7	16	5	8	6	5	5,816
	Little-cropped	49	2	7	4	−2	5	4	5,118
	Long fallow	20	3	10	5	−3	−7	5	6,050
Maize and guinea corn	Much-cropped	19	25	26	6	13	20	7	1,401
	Little-cropped	8	10	27	7	7	14	8	1,923

nitrogen shortage may be due to the fact that the seed tuber planted into the mound, weighing about ¼–½ lb., contains a reserve of nitrogen which is sufficient to tide the plant over the period of most acute nitrogen deficiency; and also that the nitrogen content of yams is about 1 per cent. (on dry weight), compared with about 2 per cent. in cereals. It is also possible that land planted to yams was not so deficient in nitrogen as land which had been planted to cereals in the experiments, owing to differences in preparing the land. For yams on new sites the grass is burnt in the early part of the dry season and the land is then hoed into circular mounds about 2 ft. high into which the yams are planted. For cereals, the grass has been burnt late in the dry season and the soil made up in shallow ridges about 9 in. high. The earlier clearing and more thorough aeration in the yam mounds may allow the period of acute nitrogen deficiency to pass before the rapid growing time in the rainy season. Studies of comparative nitrate levels have not yet been made.

Comparison of the Voltaian sandstone region with the northern granitic region.—The responses of mixed maize and guinea corn to nitrogen shown in Table 2 were very similar to those of early millet and guinea corn in the far north (see Part II, this *Journal*, 1953, **21**, 262), if allowance is made for the substantial differences in the yield of guinea corn. On the other hand, phosphorus responses on the sandstone areas were considerably and significantly lower than those on the granitic areas with the cereals, and somewhat lower with the groundnuts. A sufficient explanation is that the sandstone sites are, on the average, fallowed for as long as they are cropped, while most of the granitic sites are cropped continuously; but the possibility that the granitic sites are inherently poorer in phosphorus cannot be ruled out.

Variation in responses between areas.—The responses and mean yields in the different areas are compared in Table 4.

With yams, the mean yield at Tamale was poor and significantly less than at Yendi, which may be explained by the lower rainfall in the Tamale area; however, no explanation can be offered for the significantly ($P = 0{\cdot}05$) poorer response to nitrogen. The phosphorus responses in the Wenchi and Ejura areas were significantly below those in the

TABLE 4. *Area Responses, Mean Yields, and Seasonal Average Yields*

(*lb. per acre*)

Area	*No. of sites*	*Responses*						*Mean yield*	*S.E.*	*Seasonal average*
		N_1	N_2	*S.E.* (N_2)	P_1	P_2	*S.E.* (P_2)			
					Yams					
Tamale	30	88	87	146	392	622	198	4,182	338	6,700
Yendi	23	330	886	252	144	538	221	6,010	344	6,700
Wenchi	18	589	715	504	−859	−516	375	6,754	881	11,900
Ejura	9	−65	696	411	−447	−1,139	663	6,333	744	11,900
					Maize and guinea corn					
Tamale	25	202	239	72	84	211	98	1,440	154	540 (Maize)
Yendi	14	297	444	118	95	175	77	1,305	191	620 (G. corn) 1,160 (Total)

Tamale and Ejura areas, which may be explained by the fact that most of the sites at Ejura and Wenchi were 'long-fallow' sites on which phosphorus is not required, as noted above. With maize and guinea corn there were no striking differences between the areas, though the responses to nitrogen was once again lower in the Tamale area, but not significantly so.

Seasonal variation in yield.—No crop-yield surveys on native farms extending over a period of years have been carried out in these areas, and consequently there is no reliable information about the average annual yields. The last column of Table 4 shows the average yields over a number of years at experimental stations, no account being taken of mixed cropping. The yield of yams in all areas was below the average. The rainfall during the year was about 17 in. below the normal in the Tamale and Yendi areas and 9 in. below the normal in the Wenchi and Ejura areas, which explains the reduced yield of yams. The cereals are more sensitive to the distribution of the rainfall, which was particularly favourable for guinea corn, and this accounts for the yields being up to the average. It may therefore be assumed that the fertilizer responses obtained with yams in the year 1950 were somewhat below the average responses that would be obtained over a number of years, and the responses with cereals were about the average.

The best use of fertilizers in the Voltaian sandstone areas.—The diffi-

culty of attaching a precise value to fertilizers for use among small subsistence farmers, which has already been considered for the far north (see Part II), applies equally to this region.

In the following assessment the prices of fertilizers and the value of produce were taken as follows (all per cwt.): sulphate of ammonia, 36*s.*; superphosphate, 29*s.*; yams, 8*s.*; cereals, 17*s.*; groundnuts (shelled), 40*s.*; rice (paddy), 34*s.* The last three were guaranteed minimum prices.

The residual effect of sulphate of ammonia on cereals in the year following application has been estimated conservatively at 25 per cent. of the direct effect, as a result of a series of trials at experimental stations.

For the main crops of the region, yams and cereals, two methods of using sulphate of ammonia emerge from these experiments:

(*a*) Apply 120 lb. per acre of sulphate of ammonia to the yam mounds. Besides the increased yield of yams there will be increases with any other cereals interplanted with the yams, and the residual effect on cereals in the second year. The expenditure and return are estimated as follows: Expenditure, 120 lb. of sulphate of ammonia at 36*s.* per cwt. = 39*s.* Return, direct effect: 527 lb. yams at 8*s.* per cwt. = 38*s.*; 1 cwt. (approx.) interplanted cereals at 17*s.* per cwt. = 17*s.*; residual effect: 78 lb. mixed cereals at 17*s.* per cwt. = 12*s.* Total return = 67*s.*

(*b*) Apply 60 lb. per acre of sulphate of ammonia to mixed maize and guinea corn. Expenditure, 60 lb. sulphate of ammonia at 36*s.* per cwt. = 19*s.* Return, direct effect: 236 lb. mixed cereals at 17*s.* per cwt. = 36*s.*; residual effect: 59 lb. mixed cereals at 17*s.* per cwt. = 9*s.* Total return = 45*s.*

It is doubtful whether farmers could be persuaded to adopt the first method as the nitrogen has no noticeable effect on the foliage of the yams and the increased yield of only 10 per cent. would not be obvious to them. The second method has the advantage that the initial outlay is smaller and the effect of the nitrogen on the leaves of the cereals is marked.

Sulphate of ammonia will certainly pay on rice. It was unfortunate that so many of the trials on this crop were spoiled, and the error is too high to make positive recommendations about rates of application without further trials.

Groundnuts are not a major crop in this region. In the Tamale area, the response to 120 lb. of superphosphate—202 lb. kernels—though not so great as in the far north, is highly profitable, and if farmers in the far north are encouraged to use superphosphate there is no reason why groundnut farmers in the Tamale and Yendi areas should not be similarly encouraged. Further experiments may, however, show that it will be more economical to apply sulphur than superphosphate.

The scope for sulphate of ammonia in the Voltaian sandstone area is comparatively small, it being estimated very approximately that 30,000 acres of cereals could profitably receive a dressing of 60 lb. per acre each year, which would yield a profit of about £40,000.

The Southern Maize Areas

The situation of the three areas—Krobo, Nsawam, and Keta—was described in Part I. They contain the most important maize-growing

regions of the south of the country. Their climate, natural vegetation, and agriculture are similar, and differ considerably from those of the areas already considered.

Area boundaries

Krobo. Longitudes 0° 15′ W. and 0° 00′, latitudes 6° 25′ N. and 6° 05′ N.
Nsawam. Longitudes 0° 30′ W. and 0° 15′ W., latitudes 5° 50′ N. and 5° 40′ N.
Keta. Longitudes 0° 45′ E. and French border, latitudes 6° 00′ N. and 6° 15′ N.

Climate.—Although the total annual rainfall is less than in some of the savannah areas it is more evenly distributed (see Table 5). The relative humidity is also higher throughout the year, particularly in the dry season. The average rainfall is about 49 in. in the Krobo area, 47 in. in the Nsawam area, and from 35 in. on the coast to 45 in. in the north of the Keta area.

TABLE 5. *Rainfall Data for Selected Stations. The Southern Maize Areas*

	ABETIMA (KROBO AREA)				*NSAWAM*			
	Year 1950		*Average*		*Year 1950*		*Average*	
Month	*in.*	*Rain days*	*in.*	*Rain days*	*in.*	*Rain days*	*in.*	*Rain days*
Jan. . .	2·22	3	1·66	3	0·00	0	0·75	2
Feb. . .	3·80	4	1·60	4	1·72	3	1·88	4
Mar. . .	6·11	7	4·79	9	7·04	10	4·64	7
Apr. . .	6·23	6	5·49	9	3·03	5	4·32	7
May . .	4·89	10	6·65	11	5·10	13	6·89	10
June . .	3·29	7	6·34	14	6·80	15	8·13	13
July . .	2·82	10	4·16	8	2·51	11	2·72	7
Aug. . .	1·83	6	2·10	7	0·74	9	1·96	8
Sept. . .	2·87	10	5·53	13	0·63	10	4·13	9
Oct. . .	7·43	18	5·85	13	5·29	15	5·40	11
Nov. . .	1·99	8	2·75	9	5·25	15	4·41	10
Dec. . .	2·66	7	1·82	3	2·00	5	2·14	4
Annual total	46·14	96	48·74 (8 years)	103	40·11	111	47·37 (24 years)	92
	FENYI AKANU (KETA AREA)							
Jan. . .	1·64	2	0·76	1				
Feb. . .	2·63	2	1·33	2				
Mar. . .	3·02	6	4·86	6				
Apr. . .	7·18	6	5·11	6				
May . .	4·80	7	6·67	7				
June . .	3·46	7	8·13	8				
July . .	2·02	4	3·15	4				
Aug. . .	0·90	2	1·28	3				
Sept. . .	0·29	2	2·62	5				
Oct. . .	4·46	7	5·82	7				
Nov. . .	1·97	8	4·09	6				
Dec. . .	0·72	2	1·33	2				
Annual total	33·09	55	45·15 (22 years)	57				

Vegetation.—A consequence of the less severe dry season is that the natural vegetation is forest or thicket. When farm land is abandoned, shoots of shrubs and trees from old stumps left in the ground replace the first transient colonizing herbs, in contrast to the tall, coarse grasses in the savannah. This fact has an important bearing on the nitrogen status of the soil, for it has been found that there is a good supply of available nitrogen in land cleared from forest, in contrast to the shortage in land cleared from grass savannah.

Agriculture.—Maize and cassava are the principal crops. In the first year after clearing, maize is planted with the first rains about early April, and harvested in the uncertain mid-season dry period in late July or August. Cropping practices then vary in the different areas.

In the Krobo area the land may be left to return to bush or a crop of cassava may be planted in the late rains and harvested at intervals during the following year as required, while the bush grows up through it. There is sufficient land to allow between 5 and 10 years' rest.

In the Nsawam and Keta areas a late crop of maize is sometimes grown, its yield averaging about half that of the early crop owing to the poor and uncertain late rains. In the second year, and sometimes for a third year, this cropping is repeated. When the land shows signs of exhaustion cassava is planted and the land left to return to bush. The areas are heavily farmed; in the Nsawam area the resting period is only 2 or 3 years and in the Keta area it is between 2 and 5 years. All the areas export large quantities of maize to the big towns.

The agriculture of the Keta area has been described by Montague [5]. No studies of the other areas are available.

Soils.—The soils of the three areas differ, though all are sandy and freely draining.

The Krobo area is for the most part underlain by the Upper Voltaian coarse-grained sandstone, which forms the coarse-sandy-loam top-soils already described for the Wenchi area. The remainder of the farmed soils overlie Akwapimian Quartzite from which very similar soils develop. As in the Wenchi area the topography is steep.

The Nsawam area is underlain by granitic rocks of the Basement Complex. The topography is gently undulating and the farmed soils lie on all elements of the slopes above the seasonal flood-level in the valleys. The top soil is typically a loose, brown, loamy, coarse sand overlying a more compact sandy clay subsoil with an accumulation of quartz and ferruginous gravel at between 6 in. and 36 in. depth.

The densely farmed part of the Keta area overlies unconsolidated limonitic sandy clays. The area is gently undulating and most of the farming is on the crests and slopes above the valleys which lie rather wet. The top-soils are reddish-brown sandy loams which merge into a red sandy clay at depth. Concretions are occasionally present though they rarely interfere with root development.

Experimental Results

Unfortunately, maize rust caused havoc in these areas, the average yield being about one-third of the annual average in the Krobo and

Nsawam areas, and one-eighth in the Keta area; consequently these results do not have the same value as those of the other regions. The responses in the three areas expressed as a percentage of the mean yields are shown in Table 6.

The effects of sulphate of ammonia were moderate, and further trials in the Nsawam and Keta areas, where cropping is intensive, may show its use to be justified. The effects of superphosphate were substantial. The results in the Nsawam area were in agreement with those which had been obtained in trials at experimental stations on the southern

TABLE 6. *Response of Maize to Fertilizers in the Krobo, Nsawam, and Keta Areas*

Area	*No. of sites*	*Responses (per cent.)*						*Interaction (per cent.)* $N_2 \times P_2$	*Mean yield (lb. per acre)*	*S.E.*
		N_1	N_2	*S.E.* (N_2)	P_1	P_2	*S.E.* (P_2)			
Krobo	9	−2	2	18	29	31	14	−8	424	168
Nsawam	23	5	14	6	17	35	8	−11	580	80
Keta	29	18	14	9	9	23	9	−15	151	22
		Growth marks (per cent.)								
Krobo	9	7	2	6	12	15	6	12	..	..
Nsawam	23	6	7	3	9	16	3	1	..	..
Keta	29	23	14	3	11	22	6	−14	..	..

granitic soils [2], but no trials had previously been conducted in the Keta and Krobo areas.

There is a possibility that the percentage fertilizer effects on this diseased crop were very different from those that would be obtained on a disease-free crop; for example, if the phosphorus-treated plots were more mature when the attack developed its consequences on these plots might have been less serious. Fortunately there was little sign of rust until the end of the second month's growth, and an indication of the fertilizer effects before the attack was obtained from the vegetative growth on each plot, which was estimated by eye in the second month on all plots, using a scale of ten marks. Previous experience of this procedure, which had always been followed on trials at experimental stations, showed that there was a very good correlation between the effect of superphosphate on the early growth of cereals and the increase in yield, but that with sulphate of ammonia an early increase in growth was often not reflected in the final yield. The growth marks shown in the lower half of Table 6 confirm the substantial responses to superphosphate, and lend support to the effect of sulphate of ammonia in the Keta and Nsawam area.

No significant differences were noted when the sites were grouped according to the numbers of years since they were rested.

The value of fertilizers to the southern areas.—The annual average yield of early-season maize in these areas is about 1,200 lb. per acre.

The season of experiment was quite abnormal, the last serious rust attack being about 15 years previously. If the percentage effects obtained in 1950 are assumed to apply to the annual average, the increased yield of grain and the cash return at 1950 prices are as shown in Table 7.

TABLE 7. *Return from Fertilizers in the Southern Maize Areas*
(at 120 lb. per acre)

Area	*Calculated increase (lb. per acre) from*		*Net cash return per acre*	
	Sulphate of ammonia	*Superphosphate*	*Sulphate of ammonia*	*Superphosphate*
Krobo . . .	24	370	..	35*s.*
Nsawam . .	170	420	..	42*s.*
Keta . . .	170	280	..	20*s.*

The prices of fertilizers are taken as: sulphate of ammonia, 28*s.* per cwt.; superphosphate, 21*s.* per cwt.

The guaranteed minimum price of maize averages 17*s.* per cwt.

Sulphate of ammonia will not pay at these prices, but superphosphate is certainly profitable. No results of trials to determine its residual effects are available for the south, but from the results on cereals in the north they may safely be assumed to be half the direct effects. If the residual effect is taken on a second crop of maize, the increase should average 180 lb., worth 27*s.* Next to maize, the most important crop in these areas is cassava. Trials on this crop are difficult to arrange because farmers are reluctant to harvest as much as ¼ acre at a time. Results from experimental stations indicate that the direct effect of superphosphate in these areas is about 15 per cent. The residual effect taken on inter-planted cassava should yield about 7·5 cwt., worth 22*s.* approximately.

It should prove relatively easy to introduce fertilizers here, at any rate in the Nsawam and Keta areas, for the farmers are better educated than those farther north, they receive a better return for their labour, and they should have more capital for investment. On the average it would be advisable for a farmer to apply 120 lb. per acre of superphosphate to the early crop maize once in every cropping cycle. It does not matter greatly whether the residual effect is taken on maize or cassava. Some farmers, on more exhausted land, may also find 60 lb. per acre of sulphate of ammonia profitable.

It is estimated that superphosphate can profitably be applied each year on the following scale:

Area	*Acreage per annum*	*Increased output: tons of maize including residual effect*	*Net return*
			£
Krobo .	5,000	1,200	15,000
Nsawam .	20,000	4,800	60,000
Keta .	20,000	4,800	60,000
Total .	45,000	10,800	135,000

Summary

A large number of small trials with sulphate of ammonia and superphosphate on cultivators' farms has been conducted on the main crops of two regions in central and south Gold Coast. In the Voltaian sandstone region it was shown that 120 lb. per acre of sulphate of ammonia would increase the present yields of yams by 10 per cent. and of cereals by 28 per cent. 120 lb. per acre of superphosphate increased the yield of yams by only 3 per cent., and of cereals by 18 per cent., though possibly owing to its sulphur content it raised the yield of groundnuts by 47 per cent. The poor response to phosphorus was in marked contrast to the northern granitic region.

Differences in responses between the four areas of the region and the effects upon the responses of the previous cropping history were examined; suggestions were made for the use of sulphate of ammonia on cereals and yams, and of superphosphate on groundnuts.

In the southern maize areas the trials were upset by a severe attack of rust, but indications of substantial responses to superphosphate and moderate responses to sulphate of ammonia were obtained.

Estimates were made of the economic value of the fertilizers in the two regions.

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(*Received 30 December 1952*)

THE PERSISTENCE OF THE EFFECTS OF WORM INFESTATION IN SHEEP

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EXPERIMENTS on the effects of worm infestation in sheep frequently occupy a relatively short part of the animal's life. In order to relate these effects, particularly those on liveweight gain, to sheep-farming practice and to express the results in terms of economic loss, it is necessary to

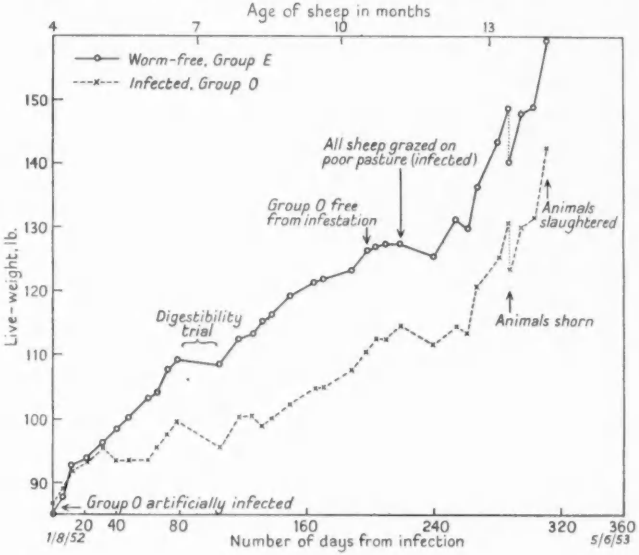

FIG. 1

know whether they persist beyond the experimental period. After an experiment of this type on lambs had been concluded, therefore, advantage was taken of the opportunity to study the subsequent liveweight gain, wool production, and carcass quality of the animals used.

Method.—Six pairs of twin lambs, Halfbred × Suffolk wethers, were raised in indoor pens in a worm-free condition, except for the presence of small numbers of *Strongyloides papillosus*, until they were weaned at 4 months of age. The lambs were then separated into two groups, (E) and (O), each group containing one member of each twin pair. One of the groups (O) was dosed with infective larvae of *Trichostrongylus axei*, the average for the group being approximately 75,000 larvae per lamb. This produced a sub-clinical level of infestation.

[Empire Journ. of Exper. Agric., Vol. 22, No. 85, 1954.]

The original experiment was reported elsewhere [1] but it may be stated that in the first 10 weeks after dosing, the infected group gained an average of 10·9 lb. per head, while the worm-free controls gained 22·6 lb. per head, a difference of nearly 12 lb. The animals were maintained in indoor pens without reinfection until 1 year old, and their liveweight production was studied to ascertain how long this trend

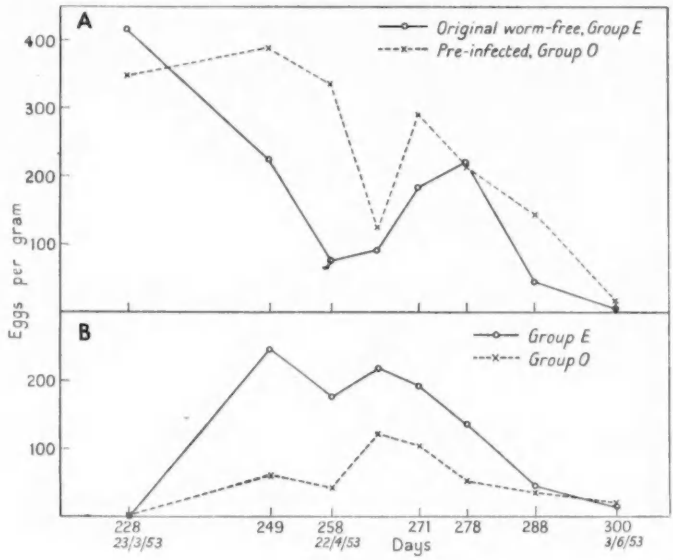

FIG. 2

continued and whether the infected animals subsequently made up the difference caused by their initial infestation.

Results.—The liveweight production of both groups is shown in Fig. 1. The first experiment lasted until the 70th day and was followed by a digestibility trial which ended on the 105th day [2]. From then on until the 165th day the difference in liveweight gain increased to 17 lb. per head. The infected group then gained weight more rapidly, but on the 198th day, when the infestation, as judged by egg-counts, had died out, the difference between the groups was still 16 lb. per head. On the 219th day both groups were turned out to graze contaminated pasture. The latter was considered to be fairly heavily infected, since it had been regularly grazed by sheep over a period of some years. The object of turning the sheep out to graze in this way was to study the persistence of effects under conditions of reinfection and also to compare the resistance of worm-free animals with that of animals subjected in their early life to a sub-clinical infestation. Fig. 1 shows that the liveweight curves for both groups were similar and that the difference between groups at slaughter, on the 315th day, was 17 lb. per head. The average egg-

counts of the two groups are shown for *Strongyloides papillosus* in Fig. 2A, and for 'Other strongyles' in Fig. 2B.

The animals were shorn on the 291st day, when the worm-free controls yielded more wool than their pre-infected twins. The average fleece weight per head from the controls was 8·4 lb., and from the infected sheep 7·2 lb. This represents a difference of approximately 15 per cent. Such a depression of wool production in infected sheep is in agreement with the findings of Carter, Franklin, and Gordon [3]. Carcass-quality measurements indicated that the amount of bone, fat, and muscle was reduced in the infected animals.[1] The chief effect appeared to be on the muscle. The average cold carcass weight of the two groups was 67·3 lb. for the infected, and 78 lb. for the worm-free sheep.

Discussion.—The liveweight increase data showed that, under conditions of reinfection and under conditions where no reinfection occurred, the effects of a worm infestation shortly after weaning persisted in sheep for periods up to one year. The infected sheep did not appear to 'catch up', even after the infestation had been eliminated. This persistence of effects is in agreement with the general statement by Hammond [4] that 'a check in growth received in early life affects the ultimate size of the animal', and with the work of Hughes, Tayler, and Everitt [5] on out-wintered groups of sheep fed on hay, silage, and foggage. Demonstration of the persistence of such effects increases the validity of conclusions based on relatively short liveweight experiments and their application to farming practice. The effects of worm infestation appeared to be reflected in fleece weights and proportions of fat and muscle at slaughter, 120 days after the original infestation died out.

The results also have considerable bearing on the problem of age resistance. It would seem doubtful that an acquired resistance could be assumed in the pre-infected group. The initial infection was carried out using a single species of worm (*T. axei*) while the reinfection occurred on pasture and would involve a variety of nematode species. In addition, the pre-infection occurred a considerable time before any reinfection took place.

The pre-infected animals, however, did appear to have a slight advantage in that their egg-counts after grazing contaminated pasture were at a lower level than those of the worm-free controls (Fig. 2B) except for *Strongyloides papillosus* (Fig. 2A). This advantage might have been expressed as a resistance to the establishment of larvae, resulting in a lower worm-burden, or as a resistance to the established worm-population, resulting merely in a lowered egg-output. Post-mortem worm-counts were extremely low and indicated no significant differences between groups.

From the results obtained during the grazing period of the experiment it is indicated that the worm-free controls suffered no measurable check to their growth. Their liveweight gain appeared to be unimpaired in comparison with that of their pre-infected twins. The check on going out to pasture (days 210 to 240) was suffered equally by both groups.

[1] The author is indebted to Mr. J. C. Tayler, Grassland Research Station, for the carcass-quality studies on which these results are based.

It was to be expected in view of the poor quality of the heavily grazed pasture on which they were first placed and was in some measure due to the change of feed. The egg-counts, even of the control animals, remained at a low level and, after a short time, declined markedly. The experiment would appear to indicate, therefore, that at 12 months of age the sheep used were sufficiently protected by a resistance due solely to age. Taylor [6] showed evidence in the early life of lambs, certainly in the first 2 or 3 months, of acquired immunity to the effects of parasitism. It was suggested that the longer survival of lambs that were 19 to 22 weeks old when exposed to infection might possibly indicate the development of an age immunity at about this time.

It would appear, therefore, that age resistance becomes fully operative between 5 and 12 months of age, in sheep exposed to infection by grazing.

Summary.—The persistence of the effects of worm infestation was studied in sheep, using worm-free controls and their infected twins, under conditions of no reinfection and continuous reinfection by grazing.

It was found that adverse effects on liveweight gain, wool production, and carcass quality persisted for periods up to 1 year.

The resistance, as reflected in liveweight gain, of worm-free sheep was studied when they were subsequently exposed to infection by grazing. The results indicated that age resistance was fully operative at 12 months of age under these conditions.

Acknowledgements.—The author is indebted to Dr. William Davies for facilities to carry out the work, to Mr. G. Pearson Hughes for his advice and interest, and to Mr. T. H. Brown for technical assistance.

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(*Received 31 December 1953*)

LONG-TERM FLUCTUATIONS IN POPULATIONS OF WHITE GRUBS (*PHYLLOPHAGA* SPP.) IN SOD IN EASTERN ONTARIO[1]

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THE white grubs, *Phyllophaga* spp. (Coleoptera: Scarabaeidae), cause much damage to grass and arable crops in North America, whilst the adult beetles attack the foliage of many cultivated and forest trees. The life-history, distribution, brood rhythm, and economic importance of *Phyllophaga anxia* (Lec.) in Quebec and Ontario have been reported

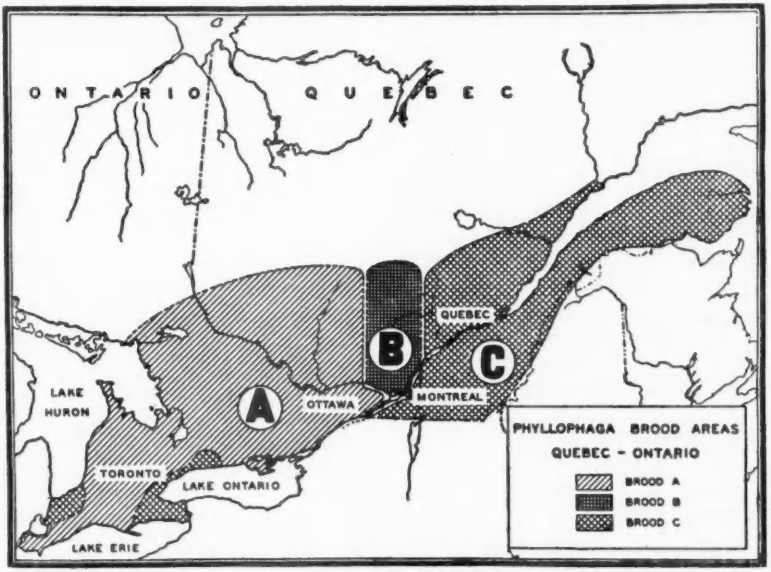

FIG. 1. Distribution of broods of *Phyllophaga* spp. in Ontario and Quebec Provinces. (For brood letters, see text)

elsewhere [1]. Three brood areas have been recognized (Fig. 1, A, B, and C); there is a uniform 3-year life-cycle, described below, with no overlapping of generations within a brood area. However, in area A the stages of the life-cycle occur one year ahead of those in area B, and in area B they occur one year ahead of those in area C. Additional data on *P. anxia* and *P. fusca* (Froel.) [2] and a general account [3] of the infestations in Ontario for 1942 have also been published. Miner [4] gave an account of the biology of a white grub, *P. crassissima* (Blanch.), in

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[Empire Journ. of Exper. Agric., Vol. 22, No. 85, 1954.]

Arkansas. He applied the term 'callow' to those beetles, newly emerged from the pupae, that remain in the soil until the following spring.

Since 1929, when the rhythm of broods of *Phyllophaga* spp. was determined for eastern Ontario [1], it has been possible to forecast the years of beetle flights and of white-grub occurrence; no important deviation from the 3-year life-cycle has been observed or reported in any brood area. However, it is not possible to forecast the intensity of outbreak or the severity of damage.

The stages in the 3-year life-cycle of *Phyllophaga* spp. in eastern Ontario are briefly as follows: in the first or flight year the beetles come out of the soil, feed on foliage of trees and shrubs, and return to the soil to oviposit. The eggs hatch and the first-instar larvae feed on rootlets of plants, develop to the second instar, and, after feeding for a short time, retire to the subsoil for the winter. In the second year, known as the white-grub year, the second-instar grubs work their way up to a few inches below the soil surface in the early spring, feed for a short time, and develop to the third instar in July. The third-instar grubs feed voraciously on the roots of plants, destroying pastures, hay meadows, crops, and even young trees and shrubs. They retire to the subsoil for the winter. In the third year, the third-instar grubs feed very little, many of them remaining in the subsoil. They pupate in July, and the beetles emerge from the pupae in September and October but remain in the subsoil until the following spring.

The present paper describes population studies conducted for 12 years in an experimental area at Marmora, Ontario, to determine the fluctuations in numbers between generations and the decline in population from the first to the third year in each generation, under three conditions of soil and vegetation. *P. anxia* and *P. fusca* occur in this area with life-histories and habits so similar that they are considered together.

Materials and Methods

An infested old hillside meadow, in which the soil type and soil moisture varied from the high to the low ground, was selected for the experimental area. A mixture of deciduous trees of various sizes bordered the area on all sides, so that food for the beetles was readily available. Hence beetles emerging from the field to feed on trees were likely to return for oviposition.

The meadow area was readily divided into three contrasting ranges designated as high, intermediate, and low. A block of eighty contiguous plots, each 20 by 25 ft., was established in each range. Population counts were made annually from 1938 to 1949 on the basis of one sample of one-quarter of a square yard per plot at depths ranging from 6 in. to 2 ft., depending on the position of the insects in the soil. The records for the first year in each generation were taken after the hatching of the eggs was completed. During the 12 years, the samples were taken in the same manner, the soil being removed with a shovel and sifted by hand; the soil and grubs were returned to the spots from which they came.

The surface soil of both the high and the intermediate ranges was a moderately fine sandy loam with about 5 per cent. organic matter at the

top of the high range, increasing to 15 per cent. at the lower side of the intermediate range. Near the dividing line between the intermediate and the low ranges the surface soil changed to a dark-grey loam with 20–25 per cent. organic matter; the subsoil also changed, at a depth of 8 in., from a relatively deep sand to blue clay. Into this clay the beetles or grubs could burrow only 1 or 2 in.

The vegetation of the meadow was principally Kentucky bluegrass, *Poa pratensis* L., but Canada bluegrass, *Poa compressa* L., and some wild oat-grass, *Danthonia spicata* (L.) Beauv., were scattered over some of the higher spots. Red top, *Agrostis alba* L., was scattered unevenly over damp spots. Irregular groups of weeds grew on grub-damaged areas, especially in the year following injury. Blueweed, *Echium vulgare* L., sheep-sorrel, *Rumex acetosella* L.; common St. John's-wort, *Hypericum perforatum* L.; mullein, *Verbascum thapsus* L.; evening-primrose, *Oenothera biennis* L.; and toadflax, *Linaria vulgaris* Hill, were incidental species. The principal summer weed, especially after severe sod injury, was the ox-eye daisy, *Chrysanthemum leucanthemum* L.

In many ways the experimental field was typical of the locality, but the intensity of infestation by white grubs during the period of investigation was somewhat below the average of the surrounding areas.

Results and Discussion

The annual population counts per square yard (averages of eighty samples of one-quarter of a square yard per range) for four generations in each range are shown in Table 1. Analysis of variance showed that the counts for the first year of each generation were greater in the high and the intermediate ranges than in the low range. However, a differential mortality in the ranges brought the totals for the subsequent years closer to each other. The extent of the differential mortality from year to year within each generation is shown in Table 1 as the percentage of the population that survived from one year to the next.

Most of the eggs of *Phyllophaga* spp. are deposited on the upper areas of slopes, as in the high range in the experimental field. The egg-laying beetles prefer a soddy surface, or a well-drained, moderately warm, light soil as well as proximity to food trees. However, bottom lands or areas of heavy soil corresponding to the low range are seldom free from oviposition, especially on raised knolls composed of light surface soil. Because it is impracticable to find and count eggs in the soil, the initial population of a generation is based on counts of first-instar larvae; these figures indicate the preferred oviposition sites and the establishment of the larvae.

The values of specific factors causing mortality within each of the four generations were not determined because of their complexity. During the egg stage, mortality is relatively light unless the soil is very dry. For the first 2 years, because of their proximity to the soil surface, the larvae are subject to attacks from predators, parasitic insects, and fungi. Concentrations of larvae in excessive numbers are then especially subject to cannibalism and to attack by predators, such as skunks, small rodents, and birds; and unfavourable soil conditions, particularly excessive moisture

and high temperatures in autumn and spring, cause heavy mortality. Also, some larvae starve where vegetation is destroyed. In the third summer, as most of the larvae stay deep in the subsoil, moisture and temperature conditions are relatively uniform and the natural enemies cannot readily attack them. Pupae and callow adults receive additional protection from their cells of compacted soil. Skunks, field mice, and birds are attracted to concentrations of large numbers of beetles and devour many of them as they emerge from, and return to, the soil. They also dig beetles out of the soil at depths of 1 to 2 in. Unfortunately it has not been possible to determine the numbers of beetles destroyed in this manner.

TABLE 1. Phyllophaga *spp.: Average Annual Populations, and Percentage Changes from one Year to the Next*

			Range					
			High		*Intermediate*		*Low*	
Generation	*Year*	*Year of life-cycle*	*Number*•	*Change %*	*Number*	*Change %*	*Number*	*Change %*
1	1938	1	141·5	..	108·7	..	43·4	..
	1939	2	107·7	76·1	75·5	68·8	25·2	58·0
	1940	3	33·8	31·3	35·2	46·6	21·1	83·7
2	1941	1	92·3	273·0	75·5	214·5	67·4	319·4
	1942	2	37·8	40·9	47·2	62·5	34·5	51·1
	1943	3	17·4	46·0	23·8	50·4	18·4	53·3
3	1944	1	155·3	892·5	123·9	520·5	40·8	221·5
	1945	2	93·5	60·2	71·4	57·6	33·5	82·1
	1946	3	27·9	29·8	30·9	43·2	19·4	57·9
4	1947	1	50·4	180·6	51·0	132·6	22·0	113·8
	1948	2	37·3	74·0	31·9	62·5	13·9	63·1
	1949	3	35·5	95·1	32·2	100·9	14·4	103·5

• Based on average of eighty samples of one-quarter of a square yard.

The percentage of the population surviving from one year to the next within a generation (Table 1) was largely dependent on the concentration of the larvae in the soil, the abundance of food available, and the soil moisture. In the high and intermediate ranges the soil and sod conditions were more attractive to the ovipositing beetles. However, in these ranges the bunchy character of the grasses and the lesser quantity of organic matter in the soil provided less food for a concentrated population than did the conditions in the low range. Hence the greater populations were more subject to malnutrition and to attack by predators and the percentage survival each year was less than where food was more abundant and the larvae less concentrated. However, the smaller populations in the low range, though not so subject to starvation or predator attack, were frequently reduced by excessive moisture.

The second-year grub counts were, on the average, 63 per cent. of the first-year counts in the same generation (Table 1). This ratio did not differ significantly between ranges or between generations, indicating a

relatively uniform survival rate in the initial year. The first-instar larvae are rarely so destructive as to cause a shortage of food and, though attacked by insect parasites and predators, they are less subject to attack by mammals than are larvae of later instars.

The third-year counts, which represent the survivals from the second year, when expressed as percentages of the second-year counts differed significantly between ranges, averaging 50, 61, and 75 per cent. for the high, intermediate, and low ranges respectively. Also, the results indicated a 100 per cent. survival from the second to the third year for the 1947–9 generation as compared to an average of 49 per cent. for the other three. The third-instar grubs are large and feed so voraciously that when they are abundant all available food is destroyed and malnutrition and cannibalism occur. Also, the larger grubs under such circumstances are readily attacked by predacious mammals and birds. This was true with the first three generations but the lower populations of the 1947–9 generation did not cause such extensive destruction nor were the lower concentrations so readily attacked by natural enemies.

The main factors governing the fluctuation in population from one generation to the next were the numbers of viable eggs deposited, weather conditions during and immediately after oviposition, and predators. There was no consistent relationship between the population at the end of one generation and at the beginning of the next. The number of callow beetles present at the end of a generation indicated the intensity of the beetle flight but not the numbers of grubs that would become established. Table 1 shows that the lowest third-year counts of the four generations occurred in 1943, and the highest first-year counts in 1944. On the other hand, one of the highest counts, that for 1946, was followed by an extremely low first-year count in 1947. The average increase in numbers in 1944 was 538 per cent. of the mature grubs and callow beetles of 1943, but in 1947 the increase was only 158 per cent.

These extremes were largely due to rainfall conditions during the critical periods of egg deposition, hatching, and early larval development. In 1944 the total rainfall from May 1 to August 31 was 12 in., which closely approximates the long-term average for the district; in 1947 it was over 21 in., reducing oviposition, the numbers of eggs hatching, and the numbers of first-instar larvae that became established.

The population fluctuations within the generations had little effect on the population fluctuations from one generation to the next.

Summary

Population counts of *Phyllophaga* spp. were made in an old hillside hay meadow at Marmora, Ontario, for 12 years, or four complete generations. The meadow was divided into three ranges, high, intermediate, and low, with a block of eighty contiguous 20 by 25-ft. plots in each range. Counts were made annually on the basis of one sample of one-quarter of a square yard per plot.

During the 12 years the generations remained distinct, with no overlapping and no sign of any deviation from the 3-year life-cycle.

The counts for the first year of each generation were greater in the high and the intermediate ranges than in the low range.

The percentage reduction in population from year to year varied mainly with the concentration of larvae, and at the end of each generation the populations tended to approximate each other.

Reductions in populations within each generation were largely caused by weather conditions, predators, parasites, and lack of food.

The population at the end of one generation bore no consistent relationship to the initial population of the next. Infestation in the first year of a generation was determined by weather conditions during oviposition, hatching, and establishment of first-instar larvae, and by predators attacking the adult beetles.

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(*Received 12 January 1954*)

A NEW BACTERIAL DISEASE OF MAIZE IN EGYPT

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WITH PLATE I

A DESTRUCTIVE bacterial disease affecting maize (*Zea mays*) suddenly appeared in provinces near Cairo during the summer of 1953. The disease involved many of the inbreds, single-crosses, double-crosses, and open-pollinated varieties. Field observations indicate the existence of marked varietal susceptibility and resistance to the disease.

The disease.—The first symptom appearing on the plants is premature withering of the lower leaves, preceded sometimes by a water-soaked appearance. A brownish longitudinal discoloration appears on the stalks, particularly at the base (Plate 1, Fig. 1). The inner tissues become soft at first, turning to a dry mass of easily disjointed fibres. The ear covers may be infected, becoming water-soaked and slimy. The included ears usually contain no, or malformed, grains (Plate 1, Fig. 2). The young plants may also be infected, in which case the whole plant may turn into a mass of brown rotting tissues. The roots are usually infected, becoming reddish in colour and easily cracking (Plate 1, Fig. 1).

Isolation.—Several isolations were made from affected materials received from different localities. The uppermost of the affected parts of the stalks were cut into portions 5 cm. long, dipped in alcohol, and flamed. Small pieces of the inner tissues were teased apart in glucose broth in sterile Petri dishes. The bacterial suspensions were then streaked on beef-extract agar. Isolation plates frequently revealed bacterial greyish-white colonies within 24 hours. A considerable number of opaque white and some yellow colonies also appeared in some plates.

Pathogenicity tests.—Different types of isolates were inoculated into 30–45-day-old potted plants of maize raised from surface-sterilized seeds. Suspensions of the bacteria in sterile water were inserted into the stalks with sterile glass pipettes, 3 cm. above the soil surface. The plants were then placed for 48 hours in trays containing water and covered with tin cylinders with glass tops.

Several isolates of the coliform group (greyish-white colonies) were found pathogenic to corn. Symptoms of the disease appeared within 48 hours, and the plants collapsed on the third day. From the infected plants, the same organisms were re-isolated and on further reinoculation they produced the disease.

Cross inoculations.—When the isolates pathogenic to maize were examined, it became evident that they corresponded to the coliform soft-rot bacteria. Cross inoculations therefore included these isolates together with two isolates of *Bacterium atrosepticum* (van Hall) Burg., and an isolate of each of *Erwinia carotovoram* (Jones) Lehm. and Neum., and *B. aroideae* (Townsend) Stapp, which were either isolated by the writer or obtained through the courtesy of Dr. W. J. Dowson of the Botany School, Cambridge. Inoculations were made into potted plants of potato, tomato, cabbage, cowpea, and maize as described under 'Pathogenicity

[Empire Journ. of Exper. Agric., Vol. 22, No. 88, 1954.]

tests'. Inoculations were also made into potato tubers, onion bulbs, green tomato, and marrow fruits by stabbing with a flamed needle charged with the bacterial growth and keeping the materials in moisture chambers at 30° C. The same organisms were furthermore inoculated into 1 cm. thick slices of potato cut under aseptic conditions and kept in sterile Petri dishes to which sterile water was added.

The most important feature of the results of these inoculations was that, while the maize pathogen was able to infect all the hosts susceptible to the coliform soft-rot bacteria, none of the latter was able to infect maize. The rot produced by the maize pathogen was indistinguishable from that produced by *E. carotovora*.

Description of the Pathogen

The methods used for the study of the maize pathogen were those generally employed for pure culture studies. 'Sugars' were incorporated as 1 per cent. solutions in peptone water with brom-cresol purple as indicator. Cultures were incubated at 30° C.

Morphological and staining characters.—The organism is a short rod (measuring 0·58–0·9 × 0·8–1·7 μ in hanging drops), actively motile with peritrichous flagella, usually in pairs and rarely in short chains, non-capsulated and non-sporing. It is readily stained with 10 per cent. Ziehl's carbol fuchsin or Loeffler's methylene blue, not acid-fast, and Gram-negative.

Cultural characters.—On nutrient (beef-extract) agar the growth appearing within 24 hours is greyish-white, raised, glistening, smooth, and with entire margins. On the same medium, supplemented with 2 per cent. glucose, growth is spreading and semi-translucent. On potato dextrose agar growth is feeble, opaque and white turning to creamy-white. On potato plugs, growth is creamy-white, raised, glistening, with no apparent diastatic action. In bouillon, and Uschinsky's solution, rapid turbidity, sediment, and a thin pellicle are observed. Less growth is observed in heart infusion broth.

Biochemical characters.—Acid and gas are produced within 48 hours from xylose, glucose, fructose, sucrose, raffinose, and mannitol, and within 4 weeks from lactose, glycerol, and salicin. Little or no acid and gas are formed from maltose and sorbitol. The organism does not hydrolyze starch. It is methyl-red positive and Voges-Proskauer negative or slightly positive. Indol is not formed or only as a trace, nitrites are produced from nitrates, and ammonia and hydrogen sulphide are detectable in traces only. Rapid cylindrical liquefaction is observed in gelatin stabs. In litmus milk, curd, acid, reduction of limus, separation of whey, and slight peptonization are all observed within 4 weeks.

Conditions for growth.—The organism is a facultative anaerobe. The optimum temperature is 35°–37° C., the minimum about 8° C. and the maximum about 40° C. The thermal death point is 51° C.

Identity of the Maize Pathogen

The morphological, cultural, and biochemical characters of this organism are not unlike those of *Erwinia carotovora* as described by

FIG. 1. Affected stalk and roots showing reddish discoloration and bacterial exudate ($\times \frac{1}{3}$).

FIG. 2. Infected ear with infected, water-soaked covers ($\times \frac{1}{3}$).

Burkholder and Smith [1]. Pathogenically, it is unique in being able to infect maize (*Zea mays*). The organism is thus regarded as a special form of *E. carotovora* to which the name *Erwinia carotovora* f. sp. *zeae* is proposed.

It is worth noting that this pathogen differs from *B. dissolvens* Rosen [2], the cause of a similar disease of maize in the U.S.A., in certain biochemical characters such as the ability to liquefy gelatin and the inability to hydrolyze starch. The maize pathogen, like *E. carotovora*, is further a true soft-rot organism, and in this respect differs from *B. dissolvens*, which, according to Waldee [3], neither causes any rot in vegetables nor produces the enzyme protopectinase.

Summary.—A bacterial disease affecting corn is described. The disease is ascribed to a new special form of *Erwinia carotovora*, namely, *E. carotovora* f. sp. *zeae* f. sp. nov. which differs from the former in being capable of causing the maize disease. The organism differs from *B. dissolvens*, the cause of a similar disease in the U.S.A., in some biochemical characters and also in being a true soft-rot organism which may attack other hosts beside maize.

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(*Received 19 January 1954*)

COTTON BREEDING IN THE SUDAN

PART I. EGYPTIAN COTTON

R. L. KNIGHT[1]

Contents

Part I.—Introduction. Egyptian cotton: cardinal requirements; blackarm resistance (evolution of resistance; value of resistance in Sudan Sakels); leafcurl resistance. References.

Part II.—Egyptian cotton (continued): jassid resistance; grade (association with blackarm resistance; salt tolerance; deciduous bracts; storm resistance); strength of lint; yield potential (locules per boll; ovules per locule); 'cluster' and 'short branch'; earliness; bollworm resistance. References.

Part III.—American Upland cotton: blackarm resistance; deciduous bracts; 'cluster' types; ginning out-turn; earliness and pest avoidance. Breeding methods. Summary. Key to main Sudan varieties mentioned. References.

Introduction

THE Sudan, with an area of approximately one million square miles, extends from about 3° 30′ N. Lat. nearly to the tropic of Cancer. It is bounded by Egypt to the north; Eritrea and Abyssinia to the east; Kenya, Uganda, and the Belgian Congo to the south; and French Equatorial Africa to the west. Ecologically, the country covers the complete range from bare, rainless desert in the north to broad-leaved woodland and forest in the far south, where the mean annual rainfall is over 1,400 mm.

Unfortunately, the rain areas of the Sudan lie to the south so that exportable products of this zone are penalized by high transport costs by road, river, and rail to Port Sudan. For this reason the development of the Sudan on self-supporting lines depended initially on the opening up of irrigated areas in the northern half of the country. Money accruing directly or indirectly from these areas was then used to initiate developments in the south. There are three major northern irrigated areas—the Gezira (including the White Nile Schemes), the Gash, and Tokar—and in all three cotton has firmly established itself as the cash export crop. Development of the rain areas of the south has also depended largely on cotton; today this crop comprises 80 per cent. of the country's exports, and either directly or indirectly it provides the bulk of the government revenue.

When the present administration took over the Sudan in 1898 slavery was rife, cannibalism was common in the south, and poverty and periodical famines were the lot of all but the chosen few. Medical attention did not exist and, except for village schools in the north teaching the Koran by heart, there was no system of education. Today (1952), when the Sudanese themselves are about to take over the administration of their country, all are free men, famines are almost unknown, and their

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[Empire Journ. of Exper. Agric., Vol. 22, No. 85, 1954.]

rare occurrence receives prompt attention, hospitals have been built in the main towns and dispensaries are dotted throughout the country; more and more schools are springing up and in addition, Khartoum University College has been established with its various Faculties, including Agriculture.

The prosperity which has made possible these developments stems from cotton, the 1950–1 crop of which sold for the peak figure of £65 m. Clearly it is of the utmost importance to the Sudan that this crop should be insured against violent fluctuations, since these would react directly on the whole economic structure of the country. For this reason one of the main aspects of our cotton-breeding policy has been yield stabilization by protecting the crop against the major diseases and pests.

Egyptian Cotton

Two types of Egyptian cotton are grown in the Sudan: Domains Sakel in the northern Gezira and part of the Gash, and X1730A and its derivatives in the southern Gezira, White Nile Schemes, the Gash, and Tokar. Domains Sakel is a high-quality type which was imported in bulk from Egypt and has since become acclimatized in the Sudan. X1730A is a rather coarser, higher-yielding type than Domains Sakel, although it was bred by selection from within Sakel [1]. Its main characteristics are its resistance to leafcurl and its sturdy, robust habit which enables it to 'grow away' after a blackarm attack; but owing to its lower quality it is not so well priced on world markets as Domains Sakel.

These two varieties of cotton are the backbone of the Sudan's economy. They have a ready market and, because their quality has been kept unchanged for so many years, they are bought with confidence by spinners solely on their description. Breeding policy has therefore been aimed at improving yield and disease and pest resistance of these types without in any way affecting their market qualities. It will be seen later that several of these improvements could only be achieved by crossing with different species of cotton all with an entirely different, and very much lower, lint quality. For this reason, the maintenance of an unchanged lint quality has been an extremely difficult task.

A brief description of the three areas of the Sudan in which 'Egyptian' cotton is grown is given below; more detailed accounts of the Sudan cotton crop will be found elsewhere [2, 3].

The Gezira.—The Gezira is a vast clay plain lying between the Blue Nile and the White. With its latest extension, the canalized area in the Gezira is now about one million acres, all irrigated by gravity flow from the Sennar Dam on the Blue Nile. About 250,000 acres of cotton are grown annually in the Gezira proper and a further 50,000 on the adjacent White Nile Schemes. Rainfall increases from north to south over the area so that blackarm disease (which is rain-borne) and leafcurl disease (which largely depends for its carry-over on the survival through the dry dead season of any badly pulled-out cotton roots) are usually more serious in the southern half.

Domains Sakel is grown throughout the north and X1730A is grown in the southern Gezira, because of the strong leafcurl resistance and

ability to 'grow away' after a blackarm attack which are shown by the latter. The White Nile Schemes used to grow X1730A cotton but have now changed over to its blackarm-resistant counterpart (BAR1730L.1—usually abbreviated as XL.1). Although Domains Sakel produces a better-priced lint than X1730A this would not compensate for the losses that would occur from blackarm and leafcurl were the former variety to be grown throughout the southern Gezira.

The Gash.—The river Gash rises in Eritrea and its annual flood usually reaches Kassala by late June. It is diverted into canals and used to flood large areas of the Gash Delta—an inland alluvial plain built up during centuries of previous flooding by this river. Areas intended for cotton are usually flooded for from 10 to 30 days according to soil type and as the land dries out the crop is sown. It receives no further watering but the roots follow the moisture down to considerable depths. The cultivated area varies from year to year, being dependent on the size of the flood, but on an average some 30,000–40,000 acres of 'effective' cotton are grown annually. Spacing is wide and yields are about half those obtained in the Gezira.

Approximately half the Gash is sown with X1730A and half with Domains Sakel. Were the matter solely one for the Gash Board authorities to decide, there can be little doubt that only X1730A would be grown. Sakel suffers severely from leafcurl in the Gash so that its yield is seldom much above 470–500 lb. of seed cotton per acre, compared with about 600 lb. from X1730A. Domains Sakel is grown only because the seed is required for sowing in the Gezira, it being the policy to use the Gash as a seed farm for the Gezira.

Tokar.—The Tokar Delta lies on the Red Sea coast about 100 miles south of Port Sudan. It is a flat alluvial plain deposited by the Baraka, a seasonal river that rises in Eritrea and flows from about mid-July to mid-September. The cultivable area varies considerably from year to year, but roughly 40,000 acres of cotton are a normal expectation. As in the Gash, the cotton is sown as the surface of the flooded land dries and there is no subsequent irrigation.

Until 1935 Domains Sakel was grown in Tokar; in that year it was replaced by the leafcurl-resistant X1530 which in turn gave way to its congener X1730A. Leafcurl disease was unknown in Tokar until 1930–1, but from then onwards it became increasingly severe until in 1933–4 some 50 per cent. of the crop was lost on this account [2]. Now that X1730A is grown, there is no leafcurl in the crop although the disease can readily be found on *Hibiscus esculentus* in the delta.

Cardinal Requirements

In 1930–1 the Gezira gave the lowest yield it has ever given—130 lb. of lint per acre compared with the long-term average of some 400 lb.—and this reduction was mainly due to blackarm disease. The 1932–3 season also gave an extremely poor crop averaging about 190 lb. of lint per acre: this reduction was mainly due to the virus disease, leafcurl. Then in the mid-thirties jassids began to assume epidemic proportions in the Gezira, especially in the north. This pest is at present controlled by large-scale

spraying with insecticides. A comparison of sprayed and unsprayed areas in the Gezira, where about 250,000 acres were sprayed with D.D.T. in 1952, gives some indication of the damage caused by jassids. Between 1945–6 and 1949–50, sprayed areas yielded from 0·3 to 1·6 kantars[1] of seed cotton per acre more than unsprayed areas, with an average increase of 1·1 kantars per acre over the whole period. This single annual spraying with D.D.T. has a marked effect on yield, but no one would claim that it gives 100 per cent. control of jassids, so that it is a reasonable inference that jassid damage would amount to more than 1·1 kantars per acre in the absence of spraying.

Breeding for resistance to blackarm, leafcurl, and jassid have formed the foundations of genetic research in the Sudan for some years. In addition, work is being done on problems connected with grade, strength of lint, yield potential, earliness (so as to improve grade and economize water), bollworm resistance, and finally resistance to Tokar conditions. These various lines of work are so linked that the final product will integrate all the characteristics required for any particular locality.

Blackarm Resistance

Blackarm disease (*Xanthomonas malvacearum*) is not only of importance in the Sudan: it causes damage wherever cotton is grown, except in irrigated or flooded areas which have no rain during and shortly after sowing time. The potential destructive power of this disease is illustrated by Hansford's estimate that it caused a loss of 50,000–70,000 bales in Uganda in 1929–30 [4], and Butler's assessment of the loss to the U.S.A. from this cause as 500,000 bales in 1927 [5].

The disease is spread by rain and wind and it attacks the whole of the aerial portion of the cotton plant except the flowers. In the leaves entry is through the stomata, and after a variable incubative period 'water-soaked' lesions appear on the lamina. In a susceptible type, these lesions spread and often coalesce. They are angular, being bounded by the veins, and translucent at this stage, drying later to a sooty black in Egyptian varieties of cotton, or to brownish-black in Uplands varieties. Frequently the diseased areas spread alongside the veins as bands of water-soaked tissue. Stem infection may occur from rain-splash or from infected rain-water flowing on the surface of the soil, but a common source of stem infection, especially in the Sudan Gezira, is from the leaf via the petiole. Seedlings often rot away and stem girdling of larger plants commonly causes them to break under the weight of any crop they may subsequently bear. Fruiting branches are also lost. Bolls are attacked so that the lint and fuzz of the contained seed become covered with bacterial slime—a major source of infection of the next crop.

When the writer began working on blackarm resistance in 1934, it was known that resistance existed, but there was no information as to its genetic nature though it was generally assumed to be complex. The first step was to simplify the problem, (*a*) by ensuring that all plants under examination had an equal chance of becoming infected to a similar degree, and (*b*) by a clear definition of the form of resistance on which the

[1] 1 kantar = 312 lb. of seed cotton approx.

work was to be based. Complete evenness of infection is imperative and is best obtained by spraying the plants on a standardized basis with a suspension of *X. malvacearum*. A suitable technique for doing this has been described [6].

Under the climatic conditions obtaining in the Sudan Gezira, the leaf is of great importance in the blackarm problem: stem infection is frequently secondary via the petiole, and bolls are infected, later in the season, through rain splash from diseased leaves and leaf debris. For this reason leaf resistance was taken as the primary basis in selection work. The response of the leaf tissues to infection by the bacterium and the quality and quantity of the damage done were the sole criteria adopted. It was felt that only by simplification of the problem along these lines could breeding for resistance be successfully accomplished.

There has been a certain amount of criticism from pathologists and plant breeders of this exclusive use of the leaf in assessing blackarm resistance, but the writer has shown in one series of crosses that leaf and stem resistance are correlated [7] and observation indicates that this correlation is general.

For purposes of assessing resistance, the type of attack on the leaf was classified into thirteen grades ranging from '0' (complete absence of blackarm) to grade '12' (full susceptibility). Later work showed that this scale was slightly too full at the susceptible end and grade '11' is no longer used. This system of classifying blackarm resistance has been defined and illustrated [7, 8].

The first source of resistance used was the Uganda strain B31, an American Upland variety bred by Nye. Resistance in this variety was shown to depend on two major genes, B_1 and B_2, accompanied by a weak minor gene complex [7]. Later, the partially dominant gene, B_3, was found in certain strains of *Gossypium hirsutum* var. *punctatum* and this gene was shown to be located on the same chromosome as B_2 [8]. In crosses between *punctatum* and *barbadense*, B_2 and B_3 showed 32·4 per cent. of crossovers, but in late backcrosses to *barbadense* there was no evidence of linkage (probably an indication of cryptic cytological differentiation in these two species). A further partially dominant gene, B_4, accompanied by a strong intensifier, B_{6m}, and by a constellation of minor genes, was shown to control immunity in *G. arboreum* [9, 10, 11] and a similar genetic mechanism, depending on a major resistance gene, possibly allelic to B_4, has been demonstrated in *G. herbaceum* [12]. *G. barbadense* is typically fully susceptible, but resistance depending on minor genes, unaccompanied by any major gene, occurs in the Sea Island group and a partially dominant major gene, B_5, has been found in one member of the species—a perennial *barbadense* from the West Indies [13]. Finally, the resistance of the *G. hirsutum* type, Stoneville 20, first reported by Simpson and Weindling [14], was shown to be due to the partially dominant gene B_7 accompanied by a modifier complex [15].

Resistance is not confined to the cultivated cottons, for it occurs also in the wild diploid relatives of cotton. Of these, *G. anomalum*, despite its arid habitat [16], shows strong resistance to this rain-borne disease, and several other wild species show fair resistance [17]. It was postulated on

ecogenetic grounds that much of the resistance in these wild species would be fortuitous and therefore 'simply' inherited, since there had been no selection pressure to build up a resistance complex of small genes throughout the species [18]. Part of this resistance would be due to a capacity for rapid leaf hardening—a character likely to have been built up over a long period in response to xerophytic conditions and thus probably complex. From work in progress on *G. anomalum* it appears that a large part of the blackarm resistance of this species is conditioned by a single recessive gene.

The eight known major resistance genes have all been transferred to Sudan strains of Sakel by repeated back-crossing [6, 17]. Sakel, like all New World cottons, is allotetraploid in origin, carrying in its sex cells thirteen chromosomes belonging to the A genom and thirteen belonging to the D genom.[1] Crossing with *hirsutum*, *punctatum*, and *barbadense* to transfer B_1, B_2, B_3, B_5, and B_7 was straightforward. Crossing with *arboreum* and *herbaceum* to transfer B_4, B_{6m}, and the *herbaceum* B gene was more difficult, since these two species are diploids carrying thirteen chromosomes of the A genom only. In making these latter crosses the *arboreum* and *herbaceum* parents were each doubled with colchicine, so that in hybridization F_1 plants were obtained with an AA(AD) somatic complement. These plants showed only very slight fertility, but by using large F_1 populations and pollinating all the flowers on them each day with Sakel pollen, reasonably large first backcross progenies were obtained and full fertility was regained in subsequent backcrosses.

The *arboreum* intensifying gene, B_{6m}, presented special difficulty, since this gene has no visible effect except in combination with a major blackarm-resistance gene. No attempt was made to handle this factor until reasonable fertility had been established in Sakel backcrosses involving *arboreum* as the donor parent. At this stage, all backcross plants showing full blackarm susceptibility were crossed with a synthesized Sakel strain known to be homozygous for the *hirsutum* gene B_2. In some of the resulting progenies, plants occurred having resistance much greater than that associated with B_2, and these, on being backcrossed to the B_2 type of Sakel, gave 1 : 1 ratios of highly resistant to resistant plants. Crossing was then switched to 'synthetic' Sakels carrying B_2 from *hirsutum* and B_3 from *punctatum*, and from this line of work strains are emerging which appear to be immune under field conditions [11]. It is noteworthy that Wickens, working in Uganda, has tested a Sudan 'synthetic' *barbadense* type carrying B_2 and B_{6m} and found it highly resistant under Uganda conditions [19]; from this and the Sudan observations it appears likely that blackarm can be controlled in New World cottons, in any area of the world, by synthesizing strains carrying B_2, or B_2B_3, intensified by B_{6m}.

The first blackarm-resistant varieties produced were a number of

[1] Five main genoms are recognized in *Gossypium* and these have been given the symbols A, B, C, D, and E by Beasley and others. The cultivated cottons of Old World origin (*G. arboreum* and *G. herbaceum*) belong to the A genom and the cultivated cottons of New World origin (*G. barbadense* and *G. hirsutum* with its varieties *punctatum* and *marie-galante*) are allotetraploids of 2(AD) composition.

X1730 and NT2[1] strains carrying B_2, or B_1 and B_2, and these were sent to the Medani Station in the Gezira for the cotton breeders there to grow large numbers of progeny rows, bulking together the best rows for a commercial wave of the new strain. Of these strains, BAR1730L.1, carrying B_2, is now in commercial production, about 75,000 acres having been grown in the 1951–2 season.

When the gene B_3 was discovered, it soon became apparent that it was much more valuable than B_1 and work with the latter ceased except for purely genetic research.

One major difficulty in a commercial hybridization programme is to keep the final product up to date, so that it shall be fully up to the standard of the latest straight selections. A scheme of backcrossing was designed to cover this, and, because all interspecific backcrossing with cotton had, in the past, failed to result in commercially successful types, a test was designed which could be applied at any stage to ascertain whether backcrossing had gone far enough [20].

The breeding programme for true Sakels (as distinct from X1730A or 'L' cottons) started by using NT2 strains for recurrent parents, since at that time it appeared likely that NT2 would replace the commercial type of Sakel grown in the Gezira. Blackarm-resistant NT2 types were carried to semi-commercial proportions, but were finally discarded, it having been decided that a type intermediate in quality between X1730 and Domains Sakel was not desired in the Sudan market. Crossing was accordingly switched from these NT2 types to Domains Sakel, using a Domains Sakel 'filtered' at the Medani Station as backcross parent. From this work arose BAR14/7, carrying B_2, from which was bred BLR14/16, carrying B_2 plus leafcurl resistance (see later), and finally BLR14/25 carrying B_2 plus B_3 plus slight leafcurl resistance, with its derivatives, BLR14/25.1 and BLR14/25.2.

On the X1730 side, BAR1730L.1 was succeeded by BAR4/11 and BAR4/16 in the breeding plots. These latter strains both carried B_2 and B_3, but although they heavily out-yielded X1730A under blackarm conditions they failed to yield satisfactorily in the absence of blackarm, largely because both have fewer seeds per locule than X1730A. BAR4/16 carries enough genetic variability to make the selection for improved yield reasonably easy, and 464 progenies from plants selected as having a large number of ovules per locule are being 'filtered' by the cotton breeders at Medani this (1952–3) season.

Finally, to make it easy to keep blackarm-resistant X1730 free from contamination with the resistant yellow-flowered Sakel types, an Asiatic gene for red leaves and flowers has been transferred to it in parallel with the other work. Preliminary spinning tests made by the Shirley Institute on this red, resistant X1730, carrying B_2 and B_3, appear satisfactory, and the type, under the number BAR5/6, is being filtered at Medani this season. It is of particular interest that spinning tests made by the Shirley Institute have shown the lint of BAR5/6 to be of typical 'L' quality, because this strain carries not only the gene R_2 from

[1] The NT2 group of strains arose by line selection from Sakel but were of a lint quality intermediate between that of Domains Sakel and X1730A.

G. arboreum (a type with short, harsh, 'wiry' lint), but also B_2 from an American Upland variety with a totally different class of lint from Sudan 'L' cotton, and B_3 from a *punctatum* with lint of no commercial quality whatever.

A comprehensive account of the breeding of blackarm-resistant cottons has been compiled by Mary Thomas from the Annual Reports of Shambat Station and from other published material [21].

Evolution of blackarm resistance [22].—Plant by plant, over a thousand strains of cotton (including the wild Gossypiums) have been artificially inoculated with the disease and their reaction recorded on the '0' to '12' scale. Most of these results have been published in three papers [6, 22, 23], others have only been recorded in the reports for Shambat Station, published annually by the Empire Cotton Growing Corporation. These surveys, in conjunction with the genetic data, show that India is the major centre of blackarm resistance and that the disease itself probably originated in that country. The Indian races of *G. arboreum* and *G. herbaceum* are, almost without exception, immune. Immunity and high resistance predominate in the commercial Asiatic cottons of the surrounding countries, but the general level of resistance is lower in the more peripheral areas and in perennial types.

In the New World, resistance occurs in variable material at the centre of origin of *G. hirsutum* in Central America and in the *punctatums* of the Bahamas region. The gene B_7 has been found in commercial Uplands, but it is extremely rare, nearly all Uplands from the U.S. Cotton Belt being susceptible. Resistance is rare in *G. barbadense*. Minor gene resistance occurs in Sea Islands, but apart from cases directly attributable to introgressive hybridization, major gene resistance has been recorded only once in the species (B_5). In the *hirsutums* acclimatized in the Old World, however, marked resistance is common in the Uplands and *punctatums* of India and Africa. The greatest resistance in New World cottons is found among the *punctatums* of the West African savannahs.

Resistance has spread in two waves in the commercial cottons, one in the Asiatic species, and one in those of the New World. The two Asiatic species acquired resistance first, and it was built up in India by the establishment of B_4 throughout the *arboreum* crop, and the accumulation of the intensifying gene B_{6m} and of minor genes around it until immunity was attained. A similar genetic mechanism was evolved in the other Asiatic species, *G. herbaceum*. In New World cottons, resistance genes have spread from extremely limited sources. Every case of effective resistance that has been studied, save one, can be traced to B_2 or B_3 from *G. hirsutum* var. *punctatum*, often fortified by minor genes.

The American Upland crops of India and Africa were established from susceptible types imported from the U.S. Cotton Belt. In India and West Africa these imported varieties outcrossed with resistant *punctatums* and commercial resistance was subsequently built up by introgressive hybridization. The resistance which occurs in other parts of Africa probably traces its origin to chance hybridization with an early importation of acclimatized Indian Upland.

The foundation of effective resistance has proved to be a major gene in all the cottons tested. The value of minor genes alone is strictly limited, but wherever there has been prolonged selection under epidemic attack, the main gene has been fortified by lesser genes.

Value of blackarm resistance in Sudan Sakels.—Blackarm disease still causes considerable direct damage, particularly in the southern and central Gezira, in years when the climate is suitable for the rapid spread of the bacterium. In the Gash, also, there is a moderate direct loss due to blackarm in certain seasons. Tokar, because of its climate, is almost entirely free from the disease.

At present, blackarm is controlled in the Gezira by seed disinfection with mercuric dusts, delayed sowing, root pulling and burning at the end of the crop, and field sanitation by sweeping up and burning debris—all costly and laborious measures. Because of the degree of control secured by these measures, the indirect effects of the disease are, in most seasons, more deleterious than is the direct crop loss.

In the Gezira the most important indirect effect is brought about by delaying the sowing date in order to avoid the worst blackarm period. It is widely held that this late planting considerably reduces the average grade of the crop, so that the financial loss due to this form of control is considerable. A second indirect effect of blackarm is to tie the southern Gezira, with its higher rainfall, firmly to the production of X1730A (which has the capacity of growing away from the disease), even were it to prove desirable for other reasons to grow Sakel in the south.

The Gash is being used as a seed farm in order to reduce primary infection in the Gezira seed supply. Gezira seed is sent to the Gash where it is grown for one season and then returned. This, since blackarm is not normally severe in the Gash, has the effect of 'filtering out' much of the blackarm, but it means that the Gash Board can grow only such varieties as are required by the Gezira authorities, who have to transport their seed supply 600 miles from Port Sudan, where the Gash crop is ginned. This transport cost £13,000 in 1952.

The direct value of blackarm resistance is well illustrated by a comparison of BLR14/25 (carrying B_2 and B_3) with Domains Sakel, and of BAR1730L.1 (carrying B_2) with X1730A. The data in Table 1 are from the 1951–2 replicated trials at three sites in the Gezira—in the north, centre, and south. Blackarm was negligible in the north but severe in the centre and south.

TABLE 1. *Lint Yields of Resistant* (*R*) *and Susceptible* (*S*) *Varieties, 1951–2* (*lb. per acre*)

Variety	*Resistance*	*North*	*Centre*	*South*
BLR14/25	R	455	301	263
Domains Sakel	S	462	132	104
BAR1730L.1	R	502	326	378
X 1730A	S	526	220	218

Clearly the production of blackarm-resistant Egyptian types is of considerable importance in terms of cotton output.

Leafcurl Resistance

The cotton leafcurl disease of the Sudan and West Africa is caused by a virus transmitted by whitefly (*Bemisia tabaci*). The first symptoms are small, single, swollen portions of the leaf veins. These spread and ultimately all the leaf veins become thickened. Severely attacked leaves often produce extra-foliar outgrowths (enations) from the veins on the under surfaces of the leaves. The bracts of buds and bolls are attacked and the growth of new sympodia is often suppressed so that, though the plant continues to grow, it becomes a sinuous main stem with curled-up, crumpled leaves. Such plants are sterile. The destructive potential of leafcurl disease is well illustrated by the Tokar crop of 1933–4, where this disease halved the yield [2], and by the Gezira crop of 1932–3 season, when leafcurl was largely responsible for reducing the yield from an average of some 400 lb. of lint per acre to 190 lb.

Considerable differences exist between varieties of cotton in their resistance or susceptibility. Of the two commercial types of Egyptian cotton grown in the Sudan, X1730A is highly resistant to leafcurl when grown at normal crop time in the Gezira, the Gash, or Tokar, and although this resistance breaks down at certain seasons of the year at Shambat and also in late-sown material in the Gezira, it is commercially completely adequate. It is the leafcurl resistance of X1730A, together with its ability to grow away after an attack of blackarm, and its greater robustness, which make it profitable to grow this type although it sells at a lower price than Domains Sakel.

Work by the writer has shown that resistance to leafcurl can readily be built up in Sakel types by selection, and that it depends on numerous small genes, rather than on a few major genes. Each generation of the recurrent parent used for the transference of blackarm-resistance genes was subjected to a mild selection for leafcurl resistance during each season. This meant that only a very modest selection pressure was exercised since the population was small, and each year the parent was replaced by a fresh stock of susceptible material from the Gezira. The effect of this selection was slight in early generations, as measured by a comparison of BAR14/1 (a B_2 strain selfed out after five crosses with Domains Sakel) with Domains Sakel itself. A comparison of BAR14/7, which represents the product of two more backcrosses, with its Domains Sakel control shows that in later generations progress was more rapid (Table 2). In this table, grade '0' represents complete absence of leafcurl and grade '4' represents an attack of maximum severity. These grades have been defined in detail elsewhere [24].

Two acres of BAR14/7 sown in November 1947, and having a total population of 21,157 plants, were regularly rogued for leafcurl. At the end of the season, all leafcurl-free plants were cut back to stimulate secondary growth, thereby making any latent leafcurl manifest itself. Regular leafcurl roguing was continued and by early October 1948 the population had been reduced to 632 healthy plants, but, of these, 390

TABLE 2. *Leafcurl Attack in Successive Strains of Blackarm-resistant Domains Sakel*

	Leafcurl grade					
	'0'	'1'	'2'	'3'	'4'	*Total*
BAR14/1 .	492	6	26	315	455	1,294
(per cent.) .	(38·0)	(0·5)	(2.0)	(24·3)	(35·2)	(100)
Dom. Sakel .	781	15	67	604	1,038	2,505
(per cent.) .	(31·2)	(0·6)	(2·7)	(24·1)	(41·4)	(100)
BAR14/7 .	92	65	67	38	23	285
(per cent.) .	(32·3)	(22·8)	(23·5)	(13·3)	(8·1)	(100)
Dom. Sakel .	2	3	63	99	131	298
(per cent.) .	(0·7)	(1·0)	(21·1)	(33·2)	(44·0)	(100)
BLR14/16 .	175	1	3	2	..	181
(per cent.) .	(96·7)	(0·6)	(1·7)	(1·1)	..	(100)
Dom. Sakel .	2	39	19	26	2	88
(per cent.) .	(2·3)	(44·3)	(21·6)	(29·6)	(2·3)	(100)

had not at that date set a boll on their secondary growth. These plants were presumed to be lacking in vigour and, since vigour is desirable of itself, and the lack of it tends to mask leafcurl [25], these 390 plants were pulled up. The remaining 242 plants were allowed to intercross freely, in an isolated plot, in order to build up by subsequent segregation still higher levels of minor gene resistance. They were later bulk-picked as the leafcurl-resistant component of the blackarm-resistant strain, BAR14/7. The new strain was given the number BLR14/16 [26]. Tested at Medani in the 1948–9 season it gave the following results:

	Leafcurl, per cent.
Domains Sakel . .	97
BAR14/7 . . .	79
BLR14/16 . . .	11

Unfortunately, although BLR14/16 was included in ten replicated trials spread over four seasons in the Gezira, in none of these trials was leafcurl ever sufficiently severe to affect yield appreciably. In the 1950–1 season 256 acres of BAR14/7 and 319 acres of BLR14/16 were grown in the Gash Delta, where leafcurl is commonly severe. The commercial area of Domains Sakel yielded at the rate of 365 lb. per acre, compared with 390 from BAR14/7 and 781 from BLR14/16. From the differences in leafcurl attack between these varieties it was evident that the superior yield of the BLR14/16 was due to its resistance.

BAR14/7 and BLR14/16 are of similar lint quality and both are slightly better than Domains Sakel in staple length, in hair weight, and in lea strength. These two types failed commercially, however, because of their low ginning out-turn. Neither BAR14/7, nor its leafcurl-resistant derivative BLR14/16, was regarded as a final product, since neither carries B_3 but only B_2, and the objective has always been to produce for the Gezira a B_2B_3 Sakel carrying leafcurl resistance and other qualities.

By the 1949–50 season a Domains Sakel type carrying B_2 and B_3 had been made (BAR14/21) and work was concentrated on making this resistant to leafcurl rather than on improving the ginning out-turn of BLR14/16.

Enough seed was available to sow one-third acre of BAR14/21 in January 1950. By June 50 per cent. of the plants had been culled because they showed severe leafcurl. This left 383 plants, all of which were ultimately attacked, though the symptoms were less severe. These plants, being in an isolated plot, were allowed to intercross freely to build up further resistance by subsequent minor gene segregation. Their seed was sown on 5 acres in October 1950. This material after further light roguing for leafcurl went forward as BLR14/25 for test in the Gezira. Leafcurl grading, done on a replicated trial at Medani, gave the following figures:

TABLE 3. *Comparison of Leafcurl Attack in BLR14/25 and Domains Sakel, 1951–2*

	Leafcurl grade					
	'0'	'1'	'2'	'3'	'4'	*Total*
BLR14/25 .	822	445	1,113	1,203	55	3,638
(per cent.) .	(22·6)	(12·2)	(30·6)	(33·1)	(1·5)	(100)
Dom. Sakel .	363	491	1,077	1,373	147	3,451
(per cent.) .	(10·5)	(14·2)	(31·2)	(39·8)	(4·3)	(100)

Seed from 1,500 plants of BLR14/25 which had survived a further heavy roguing for leafcurl (with a 50 per cent. elimination) was sent to Medani where it was grown by the cotton breeders in progeny rows. Each progeny was tested for ginning out-turn, staple length, and lint appearance and 'feel'. No roguing for leafcurl was carried out and the best progenies, numbering 235, were bulked as the first filter of BLR14/25 and given the number BLR14/25.1.

Two acres of BLR14/25.1 were sown at Shambat in March 1952. At sowing time 400 cut-back leafcurl-infected plants were transplanted within the 2 acres, and one acre of *Dolichos* (lubia) was sown alongside to build up the whitefly (*Bemisia*) population. By mid-September 2,571 leafcurl plants had been removed, leaving 5,951 healthy plants which were bulked as BLR14/25.2.

The relative leafcurl resistance of BLR14/25, BLR14/25.1, and BLR14/25.2 will be tested at the Medani Station this (1952–3) season. Meanwhile BLR14/25.2 is being reselected for resistance at Shambat.

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(*Received 18 August 1953*)

COTTON BREEDING IN THE SUDAN

PART II. EGYPTIAN COTTON (*continued*)

R. L. KNIGHT

Jassid Resistance

As knowledge of the genetic basis of blackarm resistance accumulated (see Part I), it became possible to reduce the work on this aspect of cotton breeding, and an investigation of the third problem—jassid resistance—was started. It was known, largely as a result of the research done by Parnell and his co-workers, that jassid resistance depends on a covering of hairs of adequate length and density on the under surface of the leaves.

Since X1730A and Domains Sakel are almost glabrous, the essential step was to devise a technique whereby hairs of adequate length and density could be transferred to these two varieties. Seven hairy types were chosen as donor parents for use in this work—Tanguis and Carpulla from *G. barbadense*; MU8b, Kapas Purao, and Philippines Ferguson from *hirsutum*; St. Ignatius from *marie-galante*; *G. tomentosum*; and a *punctatum* cotton. Later, Simson's *hirsutum* mutant type, T611, was added to the list together with Hairy Giza 36 (a *barbadense* from Egypt), Multani (an *arboreum* from India), and Wagad 8, a *herbaceum* from India.

Two separate breeding methods were used for each type: (*a*) straight transference by backcrossing, designed to deal solely with any major hairiness genes which might appear, and (*b*) a modified system of backcrossing designed to transfer minor gene complexes. It was shown [27] that the hairiness gene H_1 provides the core of jassid resistance in the *barbadense* varieties Tanguis and Carpulla, in Kapas Purao, Philippines Ferguson, and MU8b (*hirsutum*), St. Ignatius (*marie-galante*), and in *punctatum*. In the *barbadenses* H_1 was accompanied by a number of minor genes with direct effect, whereas in the *hirsutums* (including its var. *marie-galante*) resistance was achieved mainly by intensification of H_1 by modifiers. In Kapas Purao and Philippines Ferguson and in the *punctatum* type tested, H_1 was closely linked with the chlorophyll-deficiency gene, chl_1, so that transferences of H_1 from these types to Sakel gave chlorophyll-deficient dwarfs as the homozygous hairy end-product. (Sakel carries the duplicate gene, chl_2, and chlorophyll deficients are of chl_1 chl_1 chl_2 chl_2 composition.) For this reason H_1, transferred from Tanguis to Sakel, has been used as the foundation gene in synthesizing jassid-resistant Sakels, since the Tanguis H_1 is linked with Chl_1—the allele of the chlorophyll-deficiency gene. H_2 was shown to be responsible for the pubescence of *tomentosum* [27] and of the *hirsutum* mutant, T611 [28]: because of its pleiotropic effects on lint length and plant height, this gene seems unsuitable for further work. In addition, the main gene for hairiness has been transferred from the two commercial Asiatic cottons, *G. arboreum* and *G. herbaceum*, to Sakel. The

[Empire Journ. of Exper. Agric., Vol. 22, No. 86, 1954.]
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relationship of the *arboreum* gene to H_1 and H_2 has not yet been determined, but it is phenotypically similar to H_1; the *herbaceum* gene occupies the same locus as H_1 and appears identical with it, proving that H_1 is located in the A portion of the (AD) genom. In all these transferences the recurrent parent was at first Domains Sakel, but, as black-arm resistant varieties became available, crossing was switched to B_2 types, then to B_2B_3 strains, and finally to the latest types carrying B_2 and B_3 and leafcurl resistance. The straight transference of H_1 to such types is now complete, and it has been demonstrated that this gene has no effect on lint length and quality [26].

In transferences from MU8b and Philippines Ferguson to Sakel, the full parental hairiness has been extracted from fifth and sixth backcross material respectively. The method of transference with all New World types has been to cross the hairy donor parent with Domains Sakel, extract the maximum hairiness in F_2, and backcross to Sakel. In the F_2 of this backcross, maximum hairiness is again selected for further backcrossing and selfing. Meanwhile, in each case the main H gene was transferred, backcross by backcross, without selfing out until later. As soon as this transference had gone through four or five backcrosses, an HH type was selfed out and used as a temporary backcross parent in the transference of the length modifiers and minor genes. When the identity of any particular H gene with H_1 was established, crossing was switched to a Domains Sakel strain carrying H_1 transferred from Tanguis. For this purpose JR14/5 was used as recurrent parent until BJR14/18 and, later, BLJR14/23 became available, and this has now been replaced by BLJR14/29 for the final crosses. The composition of these four successive 'synthetic' Domains Sakels is as follows:

JR14/5	H_1H_1 Domains Sakel
BJR14/18	H_1H_1 B_2B_2 Domains Sakel
BLJR14/23	H_1H_1 B_2B_2 Leafcurl-resistant Domains Sakel
BLJR14/29	H_1H_1 B_2B_2 B_3B_3 Leafcurl-resistant Domains Sakel

By using this system, no conscious effort is required to add B_2, then B_3, and finally leafcurl resistance: these additions take place automatically as a result of further backcrossing.

Where the donor parent has been an Upland (*hirsutum*) cotton, the greatest obstacle in this work has been the marked sterility of all plants having the maximum hair length and density in the straight F_2 and especially in the F_2s of the first and second Sakel backcrosses. In later backcross F_2s this sterility was broken down, but it was a serious trouble in the early generations, because these rather sterile plants needed many more cross-pollinations to obtain adequate seed for the next generation. This meant a longer growing season and consequently greatly increased danger from leafcurl and from bollworm. (No leafcurl-resistant material had entered into the parentage of these early crosses, since the resistant strains were not made until later.)

It is not yet known whether the final products of this work will be commercially successful, but enough has been done to prove that the gene complexes governing jassid resistance in MU8b and in Philippines

Ferguson can be transferred in this way. Plants with excellent hair length and density have been selfed out of the fifth backcross from MU8b and out of the sixth backcross from Ferguson, and established as pure-breeding lines fully as hairy as the donor parents.

Hairs on the under sides of cotton leaves are not the only possible source of jassid resistance. *G. armourianum*, though it has glabrous leaves, is markedly resistant or immune to jassids and, in crosses between *G.* '*armadense*'[1] and Sakel, this resistance has been found to reappear in the first backcross. Possible causes of this resistance are the citronella-like smell of *armourianum* or its leathery leaf texture.

Grade

The grade of Sakel and X1730 crops in the Gezira is second in importance only to yield. In November 1951 the difference in price between the top and bottom grades both of Gezira Sakel and of X1730 was over 3*s.* a pound. During a slump the picture is very different; all prices are lower and the premium on grade is greatly reduced. An average crop in the Gezira and White Nile areas produces roughly 150,000 bales of 400 lb. of X1730 lint and 100,000 bales of Sakel, and the average grade of the Gezira crop has varied in the last 17 years from 2·7 in 1936, down to 5·0 in 1949. If grade could be improved and seasonal fluctuations diminished there would clearly be a considerable financial advantage.

Association with blackarm resistance.—Late-sown cotton in the Gezira normally produces a crop of low grade; it was therefore suggested that sowing earlier than the present practice (mid-August) might improve grade. Early sowing is only possible with blackarm-resistant varieties—the risk would be too great with commercial Domains Sakel and X1730 because earlier sowing increases the period when the crop is subject to rain-storms, and hence to blackarm. It was suggested that blackarm-resistant strains should be given commercial trials in the Gezira with a sowing date about 3 weeks earlier than the standard.

In 1949–50 a trial of early-sown B_2 material (BAR1730L and BAR-1730L.1) versus normal sown susceptible X1730A and normal sown B_2 material was carried out by the Gezira authorities. Each treatment comprised 70 acres. The results are given below:

TABLE 5. *Comparison of Grade of Early-sown and Normal BAR1730L and BAR1730L.1 with X1730A, 1949–50*

	Mean grade	
	Early	*Normal*
BAR1730L	2·2	4·1
X1730A (control)	—	4·1
BAR1730L.1	2·5	4·7
X1730A (control)	—	3·9

[1] *G.* '*armadense*' is the hexaploid produced from the sterile triploid, *G. barbadense* × *G. armourianum*.

In view of these results, 2,800 acres were put down to early-sown BAR1730L.1 in the Gezira in 1950–1. An average grade of 3·1 was obtained for this early-sown cotton compared with 4·3 for the total X1730A zone of the Gezira and an average of 3·8 for the four adjacent blocks.

In the following season (1951–2) three blocks with a total area of about 12,000 acres were sown with BAR1730L.1. Half of this area was sown early and half at normal crop time, 'early' and late 'numbers'[1] being chosen more or less at random. The season was one characterized by poor yields and poor grade and the X1730 zone of the Gezira suffered most. The average grade for X1730 was 5·02, but so poor was the quality of the crop that the Raw Cotton Commission further down-graded it before purchasing. Under these extreme conditions early sowing had little effect on grade, the early-sown areas giving an average grade of 4·9 compared with 5·2 for the normal sowing date and 5·0 for the four adjacent X1730A blocks (sown at normal time). Early sowing had a marked effect on yield, however, giving an average return of 3·62 kantars per feddan[2] compared with 2·75 from the normal sowing date of BAR1730L.1 and a similar yield from the adjacent X1730A blocks.

A further three blocks in the Gezira have been sown with BAR1730L.1 this (1952–3) season, about half the area of each having been sown early. Until these results are obtained it can only be maintained that early sowing of blackarm-resistant strains is likely to improve grade and may at times greatly increase yield.

Salt tolerance.—In any irrigated area, salty land is apt to be a problem of some importance. The Sudan Gezira is fortunate in that although the soil is alkaline the irrigation water adds very little salt to it. Dastur [29] has shown the part salinity plays in causing 'tirak' in the Punjab and how a succession of hot, dry spells causes water strain on the cotton plants, particularly when the soil is saline. In a year of bad grade, such as 1948–9, Gezira cotton closely parallels many of the Punjab symptoms of 'tirak'. Furthermore, the Gezira crop can suffer water strain on salty land when winter temperatures are excessively low, as in 1951–2; the shorter winter days also contribute to this condition [30]. From this it seems probable that seasonal fluctuations in grade (and in yield) might be narrowed if the crop could be made more tolerant to salinity.

Certain cottons are known to show marked salt tolerance [31, 32, 33, 34, 35] and it is noteworthy that these types are usually from irrigated areas. It seems a reasonable assumption that such tolerance would be built up as a natural response to selection and that it would probably be controlled by minor genes. Work has accordingly been started on building up the salt tolerance of BLR14/25. 2 (a leafcurl-resistant strain carrying B_2 and B_3) by germinating large numbers of seeds in soil of known salinity. The standard of salinity is set so as to have a high rate of elimination and successful plants are transplanted to an isolated plot where, by panmixis followed by segregation of minor gene complexes,

[1] A 'number' in the Gezira covers approximately 90 acres.

[2] 1 kantar = 312 lb. of seed cotton approximately; 1 feddan = 1·038 acre.

they can build up still higher degrees of tolerance before their seed in turn receives saline treatment. This line of research has been undertaken by M. F. Rose, working at the Gezira Research Farm, Wad Medani.

Deciduous bracts [36].—Another possible line of attack on the grade problem is to reduce the amount of dirt in the seed cotton. The production of a cotton with involucral bracteoles which are either lacking or much reduced in size, or which shed or wither away before the boll opens, would be valuable, since much of the trash which becomes mixed with cotton consists of pieces of bracteole. The ideal type of bract is that found in some of the wild diploid relatives of cotton from the New World, notably in *G. aridum*, *G. armourianum*, and *G. thurberi*. These three species all have very small bracteoles; those of *armourianum* are shed before the flower opens, whilst in *thurberi* the bracteoles are often caducous at the time the boll opens. *G. aridum* also has very small bracteoles which are, however, persistent. Another species worthy of consideration is *G. harknessii*, the bracts of which, though larger than those of the other species mentioned, fall off when the flower opens. Finally, the African and Arabian species *G. anomalum* and *G. areysianum* both have very narrow bracts.

Crosses of *G. armourianum*, *G. thurberi*, and *G. anomalum* with Sakel (*G. barbadense*) give more-or-less sterile triploids with normal-sized persistent bracteoles. The hexaploids *G.* '*armadense*' (from *armourianum* × *barbadense*) and *G.* '*thurbadense*' (from *thurberi* × *barbadense*) also have normal-sized persistent bracteoles, as does the synthetic tetraploid *G.* '*thurboreum*' (from *thurberi* × *arboreum*). Furthermore, in 2 acres of progenies of *G.* '*armadense*' and *G.* '*thurbadense*' crossed three times on to New World types, no plants with deciduous bracts and none with minute bracts were present. Neither did any such plants appear in 1½ acres of selfed and natural material from these backcross progenies of '*thurbadense*' origin. Selfed progenies from the '*armadense*' backcrosses were not grown.

From this it seems unlikely that the small and/or deciduous bracts found in certain of the New World diploid *Gossypiums* can be transferred directly to the cultivated tetraploids. The tetraploid cottons of commerce carry an A genom deriving from the Asiatic group, and a D genom similar to that of the New World diploid *Gossypiums*. It is probable that the genes for small and caducous bracts are submerged by the A genom genes for large and persistent bracts. These potentially economic genes might be utilized if they could first be transferred to an Asiatic cotton. Thus if the small deciduous *armourianum* bract could be transferred to *G. arboreum*, the resulting 'small deciduous *arboreum*' could be crossed with *armourianum* and the product doubled to make the allotetraploid *G.* '*armoreum*'. This synthetic allotetraploid would then be homozygous in both the A and the D genoms for the genes responsible for small deciduous bracts; from it these genes might be transferred, by backcrossing, to their appropriate positions in both the A and D genoms of a commercial New World cotton. R. L. Cuany is exploring the possibilities of this line of research at Shambat. A second method of attack is to transfer the small bract of *G. anomalum* (B genom) to the A portion

of a New World (AD) genom, and the small or deciduous bract of a New World diploid (D genom) to the D portion of the (AD) genom. As a first step *G. anomalum* was crossed with BLR14/25 and the F_1 doubled with colchicine to make the hexaploid *G.* '*anomadense*'. This is now being crossed with various New World diploids with small bracts in the hope of making a BD.AD tetraploid which could then be backcrossed to the cultivated (AD) cotton. The late J. Sadd was working on this aspect of the problem at Shambat.

Storm resistance.—Although the cotton crop in the Gezira is picked at frequent intervals there is often a considerable loss in grade, particularly in the Sakel areas in the north, due to wind blowing cotton out of the bolls on to the ground. While cotton picked from the boll may be grade 1 the same cotton picked up from the ground is apt to be grade 6.

Cook and Hubbard [37] described *G. contextum* as having the inner surface of its mature carpels finely and closely wrinkled, so that the ends of some of the lint fibres are caught and held in these wrinkles. Some of the fibres appeared to them to be held by hardened exudation. It seemed probable that this character would be valuable if it could be transferred to blackarm-resistant Sakel, with a somewhat reduced expression. *G. contextum* was chosen as the donor parent rather than a commercial 'storm-proof' American Upland, since in the latter the character might have been built up by patient human selection of small differences and might thus be controlled by minor genes. *Contextum*, being a more-or-less wild cotton, was unlikely to have been subjected to a selection pressure in favour of the storm-proof character so that here the genetic control might be expected to be simple. H. D. Lynn [38] considers that storm resistance in the American Upland type, Storm Proof No 1, is controlled by a single gene, but Lynn's work did not come to the writer's attention until later.

In 1950 *G. contextum* was crossed with BLR14/16 (Sakel carrying B_2+leafcurl resistance). The *contextum* type of adhering boll proved partially dominant in F_1 [39], though its expression was very weak. This material was handed to L. C. Hughes for further work at the Gezira Farm, Medani. He is backcrossing to BLR14/25 substrains (carrying B_2+B_3+leafcurl resistance) and will make his final backcrosses to jassid-resistant material when this is available.

Strength of Lint

In 1945 Domains Sakel was crossed with *G. thurberi* and six F_1 seeds were soaked in 0·05 per cent. colchicine (misprinted as 0·5 per cent. in the original report [40]) for 48 hours. All six seeds gave rise to hexaploid plants which for convenience have been called *G.* '*thurbadense*'. Crosses were made between '*thurbadense*' and Domains Sakel (blackarm-resistant Domains Sakel was not then available); the resulting F_1 plants were remarkably uniform and were all, presumably, 65-chromosome types carrying a full *barbadense* (AA.DD) somatic complement plus a single set of 13D chromosomes from *thurberi*. These pentaploids showed very low fertility. They were used as the female parent and regularly

pollinated with Sakel pollen. Sixty-five plants were obtained from this cross, of which thirty-two were sterile and the remainder showed reasonable to good fertility.

American workers had shown that *G. thurberi* carries a potential for increased lint strength [41] although this species has no lint. Accordingly lint from the thirty-three fertile backcross plants was sent to the Shirley Institute for preliminary strength tests, and one plant was found to have a Pressley Index of 10·0.

From the next backcross 153 plants of *G. thurbadense* × Domains Sakel[3] F_1 composition were raised. Lint of these plants was tested by hand and the seventeen strongest lots were sent to the Shirley Institute. Their report gave the following figures for the three strongest plants:

Plant no.	*Pressley index*	*Effective length (32nds)*	*Standard hair wt.*
PE 26/47.18 . .	10·3	49	114
PE 26/47.23 . .	10·4	50	107
PE 26/47.135 . .	10·5	48	104
Domains Sakel .	8·6	50	121

These plants were selfed, in the hope of breeding a line pure for high strength which could then be used for crossing with the final product of the blackarm-leafcurl-jassid-resistance work. Last season (1951–2) F_4 lines were grown and two plants with strength indexes of 10·6 and 10·7, respectively (compared with 8·0 for the control), were obtained. So far, however, no line has been obtained which is pure-breeding for the character. This work has two possible uses. Firstly it gives a means of increasing the strength of Sakel by 25–30 per cent. Secondly, in jassid-resistance breeding, the transference of the full hairiness complex from Upland to Sakel might increase the fibre hair weight, thus making it an entirely different and much lower class of cotton. Should this happen, this *thurberi* material, with standard hair weights of 104–7, would provide a means of reducing it.

Yield Potential

Apart from the provision of disease resistance by hybridization, the improvement of the yielding capacity of X1730 and Sakel is largely a matter of straight selection, and such selection is already being carried out at Medani. Nevertheless, it seems probable that the process can be helped by hybridization. Thus one of the characters on which yield is ultimately based is the number of locules per boll. The transfer of 4-loculed bolls to Sakel would not necessarily increase yield immediately, but such a Sakel would obviously offer more scope for selection for high yield. The capacity of a strain to respond to selection for increased yield can also be augmented by raising the number of seeds per locule. With this end in view, *G. auritum* was obtained from America for use as a donor parent. This 'species' has up to 12–13 seeds per locule, compared with 6–7 in Sakel.

Locules per boll.—Domains Sakel has a mean number of about 3·1 locules per boll, whereas American cotton averages from 4·0 to 5·0 according to variety.

In crosses between the Upland variety, Philippines Ferguson (mean locules 4·0), and Sakel, the high locule number has been carried to the sixth Sakel backcross from which plants with a mean locule number of 3·7 have been recovered. These are being crossed with BLR14/25.1. In this transference the first three crosses were with Domains Sakel, BAR14/7 (Domains Sakel+B_2) was used for the fourth cross, and BLR14/16 (Domains Sakel+B_2+leafcurl resistance) for the last three. At this stage lines with high locule numbers could have been selfed out for commercial trial, but the objective is to incorporate the character in a leafcurl-resistant Sakel carrying both B_2 and B_3. For this reason, plants with high locule numbers in the sixth backcross are being crossed with BLR14/25.1 and this material will be backcrossed to BLR14/25.2, after which a high locule strain can be selfed out for commercial trial, and for inclusion in the breeding plots at Medani.

In 1950 an investigation was begun into the genetics of locule number in Upland × Egyptian crosses. This line of research was undertaken by the late J. Sadd, but owing to his tragic death it has had to revert to the writer. A number of Upland strains were crossed with BLR14/16 (average locule number 3·1) and this was used as the recurrent parent. In the second backcrosses, Stoneville 20 (average 4·4) gave segregates with mean locule numbers up to 3·9; Clevewilt 7 (average 4·5) gave segregates with 3·8; Punjab 268F (4·7) gave 4·0; Punjab 244F (4·6) gave 4·2; and Pubescent T611 (4·7) gave segregates with means up to 4·3. Selected plants in all these transference lines are being backcrossed to BLR14/25.1 which has a mean value of barely 3·1.

Ovules per locule.—In crosses between *G. auritum* and BLR14/16, the high ovule-per-locule number of *auritum* proved partially dominant in F_1. Unfortunately, the lateness, monopodial habit, and leafcurl susceptibility of *auritum* also proved partially dominant, so that F_1 plants cropped poorly, with the result that the F_2 consisted of only 101 plants, whilst the backcross to BLR14/16 gave only fourteen plants.

The parental varieties averaged 10·6 and 6·6 ovules per locule respectively: the F_2 gave a range from 7·1 to 9·3 with a tendency to bimodality; and the first backcross ranged from 7·1 to 7·7. Plants with high ovule numbers in F_2 were crossed with BLR14/25.1 and selfed, and selections were made in the first backcross progeny for selfing. It seems likely that the character is controlled mainly by minor genes so that fairly large F_2 progenies will have to be grown after each backcross in order to retain the value of 9·3 obtained in the straight F_2.

'Cluster' and 'Short-branch'

Because of the importance of quality, it seems unlikely that mechanical picking will ever be used in the Gezira unless a greatly improved form of picker comes on the market. Also Egyptian cottons are inherently less suited to mechanical picking than are certain Uplands, because they

do not bear their crop in one or two heavy flushes. Nevertheless, the rising cost of labour in the Sudan Gezira makes it advisable to explore any possibility of applying mechanical methods of picking there.

Cluster characters in cotton are considered desirable for mechanical picking, so the transfer of the characters 'cluster' and Egyptian 'short branch' to Domains Sakel was undertaken. The former character was transferred from an Upland variety and the latter from an Egyptian type. Both characters proved almost completely recessive, so that in backcrossing the genes were selfed-out after alternate crosses to facilitate their transfer. They were thus transferred on the basis of cross-back-cross-self-backcross-backcross-self. Both transferences were taken to the third backcross F_2 stage, when it became apparent that when freed from the donor-parent background the genes had such a weak expression as to be of no economic significance. Further work on these characters was therefore abandoned [26]: should it ever be resumed, the cross-self-backcross-self system used in the transference of jassid resistance should be employed, since the full cluster character could doubtless be transferred by this means.

Earliness

Extra earliness is potentially important for Gezira cottons as a means of improving grade and of economizing irrigation water. There are three primary methods of achieving earliness in cotton: (1) bearing the first flowering branch low down on the main stem, (2) having a short maturation period from flowering to boll opening, and (3) having a short period from flower-bud formation to flowering. Evelyn [42] at Medani Station worked on the first of these possible lines and succeeded in lowering the position of the first flowering node considerably in his Sakel selections. Nevertheless, the extra earliness which can be obtained within any variety, by selection along these lines, is strictly limited.

The maturation period of the boll is too closely linked with the length and quality of the lint to provide a basis for selection in such quality cottons as Sakel and X1730. This leaves the period from flower bud formation to flowering as an obvious part of the plant's growth cycle in which to look for earliness.

Grumm-Grzimailo [43] drew attention to the shortness of the period from bud formation to flowering in the *herbaceum* variety Million Dollar, and this character seems not uncommon in Asiatic cottons. In crosses between tetraploid Multani cotton (*G. sanguineum* = *G. arboreum*) and synthetic Sudan Sakels, and also between tetraploid Wagad 8 (*G. herbaceum*) and Sudan Sakels, markedly early types appeared in some of the F_2s of the fourth Sakel backcrosses. These early plants were selfed and a number of early types segregated in F_3. The F_3 early plants, whether from the Multani or from the Wagad 8 crosses, were all of the same general type—fine wooded, small leaved, and very monopodial. Monopodiality is usually a sign of lateness; its association with marked earliness in these plants shows that their earliness was not due to the first fruiting branch being borne low down on the main stem. Neither was it due to a shortened boll-maturation period, since earliness was assessed by

counting the number of green bolls set per plant by a certain date. This suggests that this earliness consists in a shortened period from bud formation to flowering.

These early plants have all been crossed with BLR14/25.1 and work on the character continues.

Bollworm Resistance

The whole of Khartoum Province is subject to severe bollworm damage and this 'bollworm zone' extends northwards to include the irrigation areas along the Nile all the way to Abu Hamed. The Dongola reach, farther north, is relatively free from severe bollworm attack.

Harland [44] had shown that *G. thurberi* was not attacked by bollworm either in Trinidad or Brazil. At Shambat, pink bollworm (*Platyedra gossypiella*) and Egyptian bollworm (*Earias insulana*) are regularly severe, but no other bollworms occur to any appreciable extent. Here *thurberi* was found to be completely free though surrounded by Sakel showing a 97 per cent. attack of pink bollworm [45]. A survey of bollworm attack carried out in 1946–7 [46] showed that *G. thurberi*, *G. armourianum*, and *G. somalense* all have marked resistance to pink and Egyptian bollworm.

Crosses between *thurberi* and Sakel and between *armourianum* and Sakel were several times made, but attempts to backcross to Sakel failed. It was not until hexaploids were used that backcrossing became possible. The hexaploid *G.* '*armadense*' (from Sakel × *armourianum*) arose spontaneously in 1943 from a damaged branch on a sterile F_1 plant. Five more plants of *G.* '*armadense*' were subsequently obtained by wiring sympodia on F_1 triploid plants—it was found that such wired branches occasionally produced a boll with one, or rarely two, seeds, and the seedlings which were subsequently raised from these proved to be typical '*armadense*'.

Crosses involving G. armourianum.—The hexaploid '*armadense*' plants were crossed with Sakel and with American Upland (XA129) to make pentaploids, and these were successfully backcrossed to the Sakel and Upland parent types [46]. In 1947 the following families were grown:

Family no.	*Parentage*
PE 41/47	*G.* '*armadense*' × Domains Sakel^2 F_1
PE 47/47	*G.* '*armadense*' × XA129^2 F_1
PE 42–46/47	*G.* '*armadense*' × Domains Sakel^3 F_1

In PE 41/47 there were 161 plants, of which fifty-one showed a variable measure of fertility and 110 failed to set a single boll. Several of these fifty-one plants appeared to carry bollworm resistance and these were backcrossed to Domains Sakel.

Family PE 47/47 consisted of twenty-three plants of which ten showed varying degrees of fertility. Two plants appeared to carry marked bollworm resistance, and these were again backcrossed to American Upland.

In the group PE 42–46/47, only PE 46/47 appeared to carry any worthwhile bollworm resistance. Several partially resistant plants were selected for further backcrossing [47].

At this stage, work on bollworm resistance was suspended because of the pressure on laboratory accommodation at Shambat, and this line of research was only resumed in the 1952–3 season.

Crosses involving G. thurberi.—The origin of the hexaploid, *G.* '*thurbadense*', used as donor parent in this line of transference, is given under 'Strength of Lint' (above) in which section the pentaploid generation and the first Sakel backcross are also discussed.

Bollworm damage varied greatly from plant to plant in the first Sakel backcross progeny and selections were made for further backcrossing and selfing. On the American Upland side, a presumed pentaploid progeny of *G.* '*thurbadense*' × Domains Sakel F_1 composition was bulk crossed with XA129. Some 900 seeds were produced from this cross for sowing against XA129 controls. XA129 was chosen as the parent for the initial stages of this crossing programme because it appears unusually susceptible to bollworm attack [46].

In 1947–8 season 1 acre of *thurberi* × Sakel hybrids was grown, the families being plentifully interspersed with Sakel controls. Part of this material was of *G.* '*thurbadense*' × Domains Sakel^2 F_2 composition and the remainder consisted of *G.* '*thurbadense*' × Domains Sakel^3 F_1 lines. In addition, 593 plants of (*G.* '*thurbadense*' × Sakel) × XA129 F_1 were grown. A heavy bollworm attack was induced [47] but no worthwhile bollworm resistance was evinced by any of the Sakel hybrid progenies, although a few plants in the XA129 hybrid showed fair resistance. These latter plants were crossed with XA129 and with BAR14/7 and in the resulting families, grown in 1952–3, a number of plants appeared showing marked bollworm resistance. This suggests that in backcrossing D/AD hexaploids to New World (AD) cottons it may be important to change from the *barbadense* to the *hirsutum* genom as backcross parent, since this may facilitate the 'crossing-in' of part of the *thurberi* D genom.

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(*Received 18 August 1953*)

REPEATABILITY AND HERITABILITY OF MILK YIELD IN CROSSES BETWEEN INDIAN AND EUROPEAN BREEDS OF DAIRY CATTLE

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Introduction

THE concepts of repeatability and heritability are associated with the relative importance of heredity and environment in influencing the variations in a character. A knowledge of the repeatability and heritability of a characteristic is very helpful in determining the method of selection to be adopted, in choosing an efficient breeding system, and in estimating genetic gains.

Repeatability may be defined as the fraction of the variance that is attributable to permanent differences between individuals. It includes the additive genetic variance and also the variance due to dominance deviations, epistatic deviations, and the effects of environment that are permanent for each animal but differ from one animal to another. Heritability, on the other hand, is defined as the fraction of the variance that is attributable to the average effects of genes. Since some of the permanent differences between individuals may be non-transmissible, heritability will generally not be as great as the repeatability.

A fair number of investigations have been made in recent years to determine the repeatability and heritability of milk yield in different cattle populations in temperate countries. But corresponding studies in the tropics and sub-tropics are practically non-existent. The present analysis was therefore undertaken in an attempt to provide some estimates of the repeatability and heritability of milk yield in crosses between Indian and European breeds of dairy cattle in India.

Material

The material on which this study is based was compiled by the Animal Husbandry Bureau of the Imperial Council of Agricultural Research and published in 1941. In the Introductory Note by Kartha, it is stated that the records published 'are not "officially tested milk records" in the sense in which they are understood in other countries, but are records which are subject to surprise checks and which in the opinion of the Imperial Council of Agricultural Research are systematically and accurately maintained'. However, the records appeared to have the serious deficiency that lactations above a certain level of production only (i.e. 2,000 lb. of milk) were included for publication. Generally, this type of data would not be considered very satisfactory for genetic analysis, as the selection of offspring would impair the validity of any estimates of heritability based on them. But it was found that

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the selection was operative only in the sense that the last available record of each cow at the time of compilation of the data should have exceeded 2,000 lb., so that cows which had preceding lactations below this figure had actually been included. Moreover, the effect of selection was materially evident only in the data pertaining to the pure-bred Indian animals, while the effect on the crossbreds appeared to be negligible. This was due to the fact that, whereas, in the relatively low-producing pure-bred Indian cattle, a fairly high proportion of cows would have produced under 2,000 lb. per lactation, the corresponding number would have been very small among the high-yielding crossbreds. The average yield of the crossbreds was around 6,500 lb. per lactation, and, in consequence, cows in this category which produced under 2,000 lb. would often be culled even before they completed one lactation, so that their records would not normally be available for computing heritability. It was therefore considered that the material published in the I.C.A.R. Miscellaneous Bulletin No. 36 [1] was suitable for the analysis of the repeatability and heritability of milk yield in crosses between Indian and European breeds of cattle. Owing to paucity of data in the $\frac{1}{8}$ and $\frac{7}{8}$ crossbred groups, only the data pertaining to the $\frac{1}{4}$, $\frac{1}{2}$, $\frac{5}{8}$, and $\frac{3}{4}$ crossbreds have been analysed.

Results

Repeatability.—If it could be assumed that all the cows used in the present investigation lived under the same environmental conditions, the average correlation between different lactation records would be a suitable measure of the permanent differences between cows. But this assumption would be incorrect as there is ample reason to believe that considerable variations in management existed between herds. It would appear, therefore, that the correlation within herds would be a better measure of permanent differences between cows than that calculated on the assumption that all the cows belonged to a single homogeneous population.

The repeatability of milk yield for each crossbred group in the present data was therefore calculated as the within-herd correlation between different records of the same cow. All published records relating to the first, second, third, and fourth lactations (totalling over 3,000 records) were employed for this purpose, and the results for the different crossbred groups are tabulated in Table 1. The average repeatability was obtained by weighting each of the individual correlations by the number of records contributing to it.

The results show that the average repeatability of milk yield (the correlation between the yield of the same cow in different lactations) in the $\frac{1}{4}$, $\frac{1}{2}$, $\frac{5}{8}$, and $\frac{3}{4}$ crossbred groups was 0·58, 0·55, 0·65, and 0·4 respectively. The overall average irrespective of fraction of European blood worked out at 0·53. In other words, of the total variation in milk yields within herds, 53 per cent. is between cows and the remaining 47 per cent. is between lactations of the same cow.

As the differences between individuals in any one herd may very well be partly caused by environment, the repeatability values calculated

above cannot be said to show the degree of genetic variation. However, it is clear that the genetic fraction of the variance cannot be higher than that expressed by the coefficients of repeatability within herds, and these figures may be considered maximum values for the percentage of the total variance which is caused by heredity. In regard to most characters pertaining to dairy cattle production, the additively genetic fraction of the variance is in fact considerably lower than the repeatability.

Heritability.—The usual method of computing heritability is by calculating the correlation or regression of offspring on dam. However, in many kinds of data such as the present, where considerable differences in feeding and management practices exist between herds, the most dependable method for estimating heritability consists in conducting the analysis on an intra-sire basis and doubling the intra-sire regression of daughter's record on dam's record [2].

TABLE 1. *Repeatability of Milk Yield*

Lactations correlated	*Proportion of European blood*			
	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$
1:2	0·63	0·60	0·75	0·48
2:3	0·66	0·59	0·74	0·42
3:4	0·70	0·63	0·49	0·30
1:3	0·37	0·52	0·71	0·32
2:4	0·67	0·53	0·50	0·49
1:4	0·44	0·41	0·40	0·34
Av.	0·58	0·55	0·65	0·41
No. of animals	299	630	260	309

In the present material, the only data relating to the dams were figures showing their best yield without reference to lactation number. It was therefore not possible to employ any age-correction factors for these yields, and the intra-sire daughter-dam regressions had to be computed on the basis of the highest yield of the dam and the highest available yield of the daughter without correction for age. The heritability estimates may, on account of this, be slightly lower than the true values, but the discrepancies should not be large [3]. Unfortunately, the data were classified only on the breeding of the daughters and an adequate analysis could not be carried out in the separate groups. The average heritability, irrespective of the fraction of European blood, was found to be 0·19 on the basis of 1,102 daughter-dam pairs. This figure is in fair agreement with the estimates of heritability obtained by previous investigators from other cattle populations. It may therefore be concluded that approximately one-fifth of the total variance in the milk yields of crosses between Indian and European breeds of cattle is due to the average effects of genes.

Discussion

Any estimate of repeatability or heritability is strictly applicable only to the data from which it is calculated, since such estimates describe a

condition prevailing in a population at a given time, and they apply primarily to variance in performance of individual animals.

In the present study, the repeatability seems to be slightly higher and the heritability slightly lower than the estimates reported from other cattle populations. With repeatability as high as obtained here, the very low producers can be culled as soon as their first lactation records are available with no great risk of culling good cows. The rather low heritability, on the other hand, may indicate that only a small fraction of the phenotypic superiority of the individuals selected as parents is transmitted to the next generation. But the estimates of heritability presented here suffer from the drawback that it was not possible to standardize the yield figures for environmental influences such as season of calving, age, &c. before using them for the regression analyses. The true values of heritability in the population may therefore be slightly higher than these estimates.

The results, as they are, indicate that only about one-fifth of all the differences or roughly one-third of the permanent differences between cows are transmissible. The remaining variation is due to intangible differences caused by temporary and permanent environmental factors.

Summary

The milk records of cattle in approved dairy farms in India compiled by the Imperial Council of Agricultural Research in 1941 have been used for estimating the repeatability and heritability of milk yield in crosses between Indian and European breeds of dairy cattle. The average intra-herd repeatability was found to be 0·534. The additively genetic variance as computed on the basis of 1,102 daughter-dam pairs was found to constitute about 19 per cent. of the intra-sire variance in single records of milk production.

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(*Received 3 February 1954*)

ERINOSE OF SWEET POTATO

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The disease.—A disease which causes plants to become so hairy that they stand out as white or grey patches in a field of sweet potatoes, *Ipomoea batatas*, has been seen in many parts of the three East African Territories, in Belgian Congo and in Ruanda-Urundi. No sweet potato variety seems to be immune from it. Usually all the stems and leaves are completely coated with a thick down (Figs. 1 and 2) but, in occasional mild cases, the hairs occur more on the stems, petioles, and bases of the laminae than on the upper part of the leaf blade. If the attack is new, symptoms may be confined to one stem or part of a stem. Stems are shortened and often abnormally thick. Axillary buds develop precociously but soon become coated with a thick downy growth and cease to enlarge, or they may die. The hairs seem sometimes to be superimposed on a yellow mottle, which is an early sign of the disease soon obscured by the down. The plants later become bronzed, starting at the apexes (Figs. 1 and 2).

Similar, but less severe, diseases have been described on plant species in several parts of the world. Rolfs [1] described it on the tomato in Florida and it has also been found on this host in South Africa [2] and Morocco [3]. Grape vines are affected in the U.S.A. [4], in New South Wales [5], and in Europe [6]. Litchi (*Nephelium litchi*) suffers from it in India [7]. In Hawaii also, it occurs on litchi [8] and on potato [9]; on several varieties of maple in the U.S.A. [10] and on walnut in Austria. The disease seems not to have been reported previously on sweet potato, the most nearly related plant on which it has already been described being *Convolvulus arvensis* [11]. Although many of the diseases mentioned appear to be common, none seems to be as severe as that affecting sweet potato. In other hosts the down is usually confined to small patches on the stems or on one side only of the leaves, whereas in sweet potato the whole aerial part of the plant rapidly becomes covered with the abnormal growth of hairs.

This type of disease was originally ascribed to a fungus called *Erinium*, but more recent records show that it is invariably associated with the presence of Eriophyid mites. Sweet potatoes so affected are always infested with mites, which were not found on healthy plants. I am indebted to Dr. G. O. Evans of the British Museum (Natural History) who has identified them as being a species of the genus, *Aceria* (Keifer), of the family, Eriophyinae (Nal). Hundreds of these mites can often be found on the growing tips and in depressions at the bases of the leaf laminae. Experiments have been made to determine whether they cause the hairiness and, if so, whether they are the direct cause or are vectors of some other aetiological agent such as a virus.

Experimental results.—Mr. J. D. Jameson, who first drew my attention to the disease at the Uganda Agricultural Experiment Station at

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Kawanda, near Kampala, had observed that it was perpetuated if cuttings were taken from affected plants. I have repeatedly confirmed this.

1. Two tubers from hairy plants of different varieties sent from Kawanda and grown in the glasshouses at Muguga[1] produced only healthy shoots which remained normal over the six months for which they were kept. Ten more roots were obtained from affected plants of the local variety, *Mundoro*, in native plantations near Muguga. Each was cut into halves and one half of each was washed with mercuric chloride solution. All were then planted in boxes in the glasshouse and all remained free from abnormal hairiness. They were kept for 3 months and remained normal during that time, showing that the disease is not transmitted through the roots.

2. The disease is very easily transmitted by contact. Ten small hairy cuttings were brought from the field and their broken ends were pushed into the soil beside healthy plants growing in boxes, so that healthy and diseased leaves were touching. The cuttings took root and grew and the disease persisted in them. Within a week the previously healthy plants showed yellow patches on their leaves and the down began to appear on the younger tissues in about 10 days. Further plants were infected from these by placing their leaves in contact. In all some 137 plants of twelve different varieties have been infected by contact.

3. The mites are difficult to handle individually since they are so small that they are often lost to view behind the abnormally produced hairs. Twenty were transferred by brush to two plants each of six different varieties of sweet potato. In 3 weeks, one plant began to show symptoms and within 6 weeks, all twelve plants were hairy on the younger tissues. It was later realized that the conditions under which this experiment was done were unfavourable to the mite and symptoms may therefore have been retarded.

4. The above experiments proved the disease to be associated with the mites but did not show whether they were the direct cause or whether they were vectors of another aetiological agent. Although the absence of the disease from the roots made the latter explanation improbable, the following experiments were made. Ten experimentally infested plants, five with well-developed symptoms and five only recently infested and showing little more than yellow patches on the leaves, were put into a glasshouse which was fumigated four times, at weekly intervals, with azobenzene. In the fourth week of the experiment the new growth on all plants was normal. During the two further months for which the plants were retained, they remained healthy showing neither yellow patches nor hairs on the newer growth. Identical results were obtained when a further thirty plants which were very hairy were similarly treated. It can therefore be concluded that the disease is a direct result of irritation by the mites (Fig. 3).

5. Because it had been noticed that the disease seldom occurred in hot, humid districts, care was taken to prevent the glasshouse in which experimental plants were kept from becoming too hot. The precautions

[1] The headquarters of the East African Agriculture and Forestry Research Organization are at Muguga, which is 18 miles west of Nairobi, at an elevation of 6,800 ft.

taken proved excessive and a lower critical temperature level was apparently reached for, during the cold season when night temperatures at Muguga may fall to 40° F., the infested plants began to grow away from the disease; but, when the house was kept slightly warmer, the disease soon recurred in the same plants without further infestation.

6. This observation suggested that plants in the field might cease to show symptoms in the cool season at high altitudes. Twenty diseased and twenty healthy vines of each of two local varieties, *Mundoro* and *Keiru*, were planted in the field at Muguga and were separated by two guard rows. This experiment was set out on 20 June 1952, and the plants were watered as necessary. As this was the cool season, growth was at first very slow, but after one month, seventeen *Mundoro* plants and fourteen *Keiru* plants had produced young growth which was free from down and, by 20 August, the new growth of all the plants was free. The weather then became gradually brighter and warmer and growth quicker. By the end of October about half the previously diseased plants were again showing hairiness near their growing tips. By the third week in January the younger leaves and stems of all the plants which had been diseased when planted were again hairy, whereas the controls remained unaffected. Hairs continued to be produced until the experiment was terminated in the fourth week of February.

Importance and distribution of the disease.—Sweet potato Erinose appeared to be well known to the African wherever it occurred, but it was not known to be highly contagious. Some said they would never use affected vines for propagating since no tubers would be produced whilst others considered affected vines to be as good for all purposes as healthy ones. This difference of opinion might be due in part to the purpose for which the crop is grown. In some districts the sweet potato is used only as a root crop when loss of yield, due to infection, might well be obvious to the grower. In other places, such as the Kikuyu Reserve, the tops are repeatedly cut for fodder for goats, and about 18 months after planting, the roots are finally harvested. The African who repeatedly cuts the tops might not realize that the disease causes them to be small and stunted. The crop is not usually eaten by Europeans in Africa but a rootless variety is occasionally grown as a cattle feed.

To give some idea of the effect of the disease on the yield of roots, the experiment 6 referred to above and designed to show the effect of season on infestation was to have been left down for at least a year, but as many of the plants were stolen after 7 months, the remaining few were harvested. Roots were weighed with the following results:

Variety		*Average root weight per plant*
Mundoro	7 healthy plants	373 gm.
,,	10 infected plants	91 ,,
Kairu	9 healthy plants	250 ,,
,,	11 infected plants	49 ,,

Even in these immature plants the reduction in root formation was considerable. Had the plants been allowed to reach maturity the yield of the healthy ones would have been many times greater, and if the

infection had remained it is unlikely that the yield of the diseased ones could have increased more than proportionately.

During journeys done between November 1951 and March 1952 the disease was found to be widespread in Kenya, Tanganyika Territory, Uganda, the Belgian Congo, and Ruanda-Urundi. It was not found on the coastal plain immediately around Mombasa and Tanga, but it did occur at Muheza which is only 25 miles from Tanga and a few hundred feet higher. It was not found near Lushoto or Moshi and only a little was seen near Arusha. The north-east of the Belgian Congo and the north of Uganda seemed to be fairly free from it. It was found in all other places where the sweet potato was seen on the journeys described in a previous paper [12]. In the south-west of Uganda it was very prevalent, and in some native plantations every plant was attacked. In the east of Uganda, in a field of cuttings obviously planted only a few weeks previously, every plant was affected. Although it was not seen at the I.N.E.A.C. Station at Mulungu-Tshibinda, native crops within a few miles were severely attacked. It was found in all the plantations visited in Ruanda-Urundi and was particularly bad on the shores of Lake Tanganyika near Usumbura. There is a considerable amount of the disease in the Kikuyu Reserve in the vicinity of the E.A.A.F.R.O. laboratories, near Nairobi and in the Fort Hall District of the Aberdares. It occurs in the Teita hills.

Lime sulphur and sulphur dust have been successfully used to control Erinose in other crops such as tomato [2], and grapes [4], but in the present state of African peasant agriculture the use of insecticides is impracticable and unlikely to be economically worth while on a crop like sweet potato. When infected plants are seen, they should be removed and burnt and infested vines should never be used for propagation

Summary.—Excessive hairiness, often completely covering the stems and leaves, is the most obvious symptom of this disease (Erinose), which is widespread in parts of Africa. Plants are stunted, stems are thickened, and axillary buds, after precocious development, either cease to grow or are killed. The disease is highly contagious. Mites, of the genus *Aceria* (Keifer) of the family Eriophyinae (Nal), are shown to be the direct cause of the disease.

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(*Received 2 February 1954*)

FIG. 1. On the left, a healthy plant of a new variety produced for experimental purposes and called seedling B. On the right, a similar plant of the same age but covered with down and greatly stunted, through infestation with mites

FIG. 2. Apexes of shoots of var. *Sakolya*. On the right, from a healthy plant; on the left, from a plant infested with mites. The latter has a greatly thickened stem and bears many hairs on the stem and leaves

FIG. 3. Distal end of a diseased shoot of var. *Namujuna* after fumigation four times at weekly intervals with azobenzene. The lower part of the shoot is thickened and hairy owing to the mites; when these were destroyed, growth became normal (Photograph taken three weeks after the final fumigation.)

FERTILIZER RESPONSES IN THE GOLD COAST IN RELATION TO TIME AND METHOD OF APPLICATION

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PREVIOUS fertilizer trials had shown that substantial increases in the yields of annual food crops in the Gold Coast could be obtained from applications of sulphate of ammonia and superphosphate [1]. As a result of these experiments the conditions of soil, climate, and cropping in which responses could be expected were ascertained. The primary aim of the experiments described here was to find out how nitrogen and phosphorus fertilizers could be used most economically and efficiently. In the first series of trials described different rates, times, and methods of application, and qualities of phosphate were tried on a variety of crops. In the second series the best method of dividing nitrogen and phosphorus fertilizers among mixed crops was studied, since, in contrast to the practice in temperate climates, mixed cropping is the rule in the Guinea savannah. In the third series the residual effects of superphosphate and sulphate of ammonia, applied in the rates of application trials previously described [1], have been determined for two years.

I. *Rates, Times and Methods of Application, and Qualities of Phosphorus Fertilizers*

Experiments on the effect of different times of application of phosphate were considered to be of great practical importance to peasant agriculture. Particularly in the north, where there is a comparatively short rainy season, the busiest time for the farmer is during the earliest part of the rains when he has to hoe and plant his land as quickly as possible; and if he spends time on placing fertilizer with the seed he may have to reduce the area he cultivates. White [2], reporting on the fertilizer distribution scheme in northern Nigeria, states that around Kano peasants were throwing their fertilizer away because they decided the method of placement at sowing time was too much trouble. They were therefore advised to apply the fertilizer after germination. Farmers have also argued that it is wasteful to apply fertilizer to a seed that may not germinate. Accordingly, these experiments were undertaken to find out how long after germination fertilizer could be applied to the seedling without seriously reducing the response.

Experiments on methods of application are also important for practical as well as economic reasons. It is usually assumed that placement methods are superior to broadcasting, but it was thought necessary to test this. Broadcast applications would have the practical advantage that they could be made in the slack period at the end of the dry season. Also in mechanized farming broadcasting is a simple method of distribution.

[Empire Journ. of Exper. Agric., Vol. 22, No. 86, 1954.]

Experiments with concentrated forms of phosphate are particularly desirable in West Africa because of the high proportion of the cost borne by transport, e.g. superphosphate (18·5 per cent. P_2O_5) f.o.b. U.K. cost £13 per ton, but delivered to Bolgatanga, 600 miles from the coast, it cost £38 per ton. The cost of the equivalent amount of triple super was only £25 per ton.

Finally, it was thought desirable that all these factors should be tested over the range of concentrations likely to be used in practice.

At each experimental station on which responses to phosphorus had previously been obtained, there was in the forest area a trial on maize, and in the savannah a trial on sorghum and groundnuts. The details of the trials are as follows:

Design:

3^4 factorial: 3 Qualities × 3 Rates × 3 Methods × 3 Times;
replications: one;
blocks: nine, second and third order interactions confounded;
plot size: $\frac{1}{40}$ acre.

Treatments:

Qualities: superphosphate (18·5 per cent. P_2O_5), ammonium phosphate (56 per cent. P_2O_5), triple super (40 per cent. P_2O_5);
Rates: 0, 60, 120 lb. per acre superphosphate, or its equivalent; there are thus 27 dummy treatments;
Methods: broadcasting (Most trials were on the flat. On the three ridged trials the early application was made before ridging, and later applications broadcast over the ridge but not in the furrow);
planting line—the powder was run in a band about 4 in. wide along the rows of plants;
placement—the powder was placed with a tea-spoon about 2 in. from the seed or the base of the plant;
Times: early—shortly before planting;
medium—20 days after germination;
late—40 days after germination.

Experimental Results.—The results of the trials are shown in Table 1. In three of the cereal trials the yields were negligible because the maize was severely attacked by rust, and the sorghum did not set seed. However, it has been possible to include these trials in the table, since all plots were marked out of ten at monthly intervals, and for these trials the marks at the end of the second month's growth have been recorded instead of the yields. It has previously been shown that eye scores based on vegetative growth in the early stages are well correlated with the final yields in fertilizer trials with phosphate. The yields in all trials have been reduced to the same basis—mean = 100; thus each trial is given equal weight, provided its standard error is not too high. But the standard error in two of the sorghum trials is very high, and if severely biased average results are to be avoided a system of weighting is essential. The treatment results shown in the table have therefore been weighted inversely according to their variance; but in order to avoid giving undue

TABLE 1. *Rates, Times, and Methods of Application, and Qualities of Phosphate*

(In all trials the mean has been reduced to 100)

Site	Record	Mean yield (lb. per acre)	Rates (lb. per acre, super or equivalent)			S.E. diff. for rates	Times			Methods			Qualities			S.E. diff. times methods qualities
			0	60	120		Planting	20 days	40 days	Broadcast	Planting line	Placed	Super	Amm. phos.	Triple super	
MAIZE																
Pokoase 10	growth marks	..	83	112	105	8	123	113	88	98	125	102	104	119	102	10
Kwadaso 6 first season	growth marks	..	86	101	113	7	127	99	96	104	104‡	113	100	104	119	8
Kwadaso 6 second season	grain	255	70	116	114	15	124	116	106	121	100	125	101	120	125	18
SORGHUM																
Damongo* †11	grain	179	90	109	101	13	110	108	97	127	98	91	112	101	101	16
Manga 7	growth marks	..	88	102	110	9	100	117	101	128	96	94	109	111	98	11
Tono 6	grain	104	51	110	139	29	148	128	99	124	133	118	156	78	141	35
Zanlerigu 3	grain	102	58	106	136	27	184	100	75	117	148	97	117	122	122	33
CEREALS	weighted mean		83	107	111	4·3	120	110	96	114	108	104	107	110	109	5·3
GROUNDNUTS																
Nyankpala* 17	kernels	130	98	101	101	10	103	103	97	103	108	92	95	105	103	12
Damongo* †10	kernels	602	86	106	108	5	106	105	109	107	102	111	108	106	106	6
Manga 6	kernels	455	95	100	105	7	105	105	95	102	112	92	102	95	110	8
Tono 7	kernels	505	91	100	110	7	105	117	92	110	100	114	107	99	109	8
GROUNDNUTS	mean		92	102	106	3·8	105	108	98	106	106	102	103	101	107	4·5
ALL CROPS	weighted mean		87	104	109	2·9	113	109	97	110	107	103	105	106	108	3·5

* Planting on ridge, other trials on flat. † Inadvertently not randomized within blocks. ‡ Line-placed plots ridged in error.

emphasis to the trials with very small error, all trials with a standard error for difference between rates of 10 per cent. or less have been given equal weight. This is the procedure for arriving at the semi-weighted mean recommended by Yates and Cochran [3], and their methods of calculating the semi-weighted mean and its standard error have been followed.

On the average, the responses to phosphate were clearly highly significant on both cereals and groundnuts, but the higher rate did not give significantly greater yields than the lower rate. Accordingly, for comparing the other treatments the simple averages of the yields at the high and low rates have been taken.

Times of planting.—On cereals the application 20 days after germination was inferior to that at planting time, and the application after 40 days was significantly inferior. This result applies equally if only the four trials in which the grain yields were obtained are considered. On groundnuts there was little difference between the application at planting time and 20 days after germination, but the application after 40 days was nearly significantly poorer.

Methods of application.—The differences between broadcasting and planting-line placement were small on both types of crops; but it is interesting to note that broadcasting was nearly significantly better than seed placement on cereals and for the average of all crops, though on groundnuts the difference was smaller. It has been argued that seed placement should be particularly beneficial at low rates of application. The results for rates $\times$ methods of application for all crops (Table 2) show that at the low rate all methods were roughly equal, but at the high rate placement was nearly significantly less effective than broadcasting.

No experiments to test broadcasting against placement methods have previously been carried out in West Africa. Greenwood (priv. commun.) has found little difference between placement in a ring round the seed and placement on the ridge along the planting line. He also reports that the native practice in Northern Nigeria of planting F.Y.M. around the seedling is better than broadcasting. The success of broadcasting in these trials, contrary to expectation, is probably due primarily to the very low phosphorus-fixing capacity of these sandy soils, which is shown by the very high residual values of phosphate (see below). Prevention of fixation is one of the strongest arguments for using placement methods. Secondly, in these light soils, exposed to intense insolation, roots which have spread into areas of soil where phosphate is concentrated may well be damaged during a temporary dry spell, and the plant may respond better to phosphate more evenly distributed over the rooting range. Also carelessness in placing may well lead to the fertilizer being placed nearer to the seed than is safe.

The practical advantages of broadcasting are that it can be done during the slack period at the end of the dry season, and it is easy to mechanize. Its disadvantage compared with placement in peasant farming is that it is more difficult to recommend a dressing of say 1 cwt. per acre in a community with no standard units of weight and area, than to recommend one pill or spoonful per plant.

Qualities of fertilizers.—There were no differences approaching significance between the three types of phosphate on either cereals or groundnuts. The nitrogen in the ammonium phosphate, equivalent to about 5 lb. N per acre at the higher rate of application, may be expected, on the basis of large numbers of earlier trials, to increase the yields of cereals by about 5 per cent. This is too small to affect the conclusion that on cereals the phosphate is equally available in all three forms. For applications to cereals, therefore, ammonium phosphate, being the most concentrated fertilizer, will give the most economic direct return.

TABLE 2. *Rates × Methods of Application of Phosphate*

(Average over all trials. Mean reduced to 100)

lb. per acre super or equivalent	*Broadcast*	*Planting line*	*Placed*
60	106	105	102
120	114	110	105

S.E. diff. methods = 5·0.

On groundnuts recommendations must be made more cautiously. Since these trials were started it has been found by Greenwood in Nigeria that sulphur increases the yield of groundnuts, particularly in nitrogen-deficient areas, and single superphosphate has usually proved superior to triple superphosphate or ammonium phosphate [4, 5]. In the Gold Coast the more heavily farmed savannah soils are not seriously short of available nitrogen, and in these conditions groundnuts have shown a negative response to sulphate of ammonia. Here then, the extra sulphur in single super is probably not required, but it would be safer to use triple super than ammonium phosphate. On nitrogen-deficient soils that have long been under a grass fallow, single superphosphate may well prove most economical. Further experiments with phosphorus and sulphur are needed.

With the exception of the rates × treatments interaction already mentioned, none of the first-order interactions were worthy of note.

II. *Trials with Mixed Crops*

In the savannah mixed cropping of cereals is the normal practice, the principle being to grow an early maturing crop which can be harvested before the heavy rains, with a late maturing one which is harvested after them. In the Voltaian sandstone area the chief mixture is early maize and sorghum, and in the granite areas of the far north it is early millet and either sorghum or late millet. This series of trials was designed to find out how fertilizers should be apportioned between the two mixed cereals. Both superphosphate and sulphate of ammonia were used in separate experiments. Altogether there were eight trials with superphosphate and three with sulphate of ammonia.

TABLE 3. *Different Methods of Applying Fertilizers to Mixed Crops*

(In all trials mean = 100)

Site	Early crop							Late crop						
	Control	Fertilizer applied: broadcast	Fertilizer applied: to early crop	Fertilizer applied: to late crop	Fertilizer applied: split	S.E. diff.	Mean yield (lb. per acre)	Control	Fertilizer applied: broadcast	Fertilizer applied: to early crop	Fertilizer applied: to late crop	Fertilizer applied: split	S.E. diff.	Mean yield (lb. per acre)
I. SUPERPHOSPHATE														
Early Millet and Sorghum														
Zuarungu 7	44	117	131	148	60	52	44	68	91	114	144	83	32	84
Manga* 10	73	85	109	106	127	13	1,964	103	67	108	106	115	19	266
Tono 9	83	103	113	78	122	20	130	76	98	118	98	109	14	610
Early Millet and Late Millet														
Zuarungu 6	88	116	118	88	88	17	231	68	91	122	122	96	21	140
Manga* 8	88	95	98	112	106	17	181	94	98	94	114	100	16	325
Tono 8	..	..	..	failed	..	..	..	98	130	120	67	85	30	..
Maize and Sorghum														
Tamale 10	88	107	109	84	112	10	1,030	..	..	failed		..	..	..
Nyankpala 19	102	144	95	89	71	17	478	100	117	100	97	87	21	301
Damongo 13	90	119	93	108	87	15	240	81	97	107	112	104	11	538
Weighted mean	87	109	105	97	101	5·8	..	86	96	109	107	101	6·8	..
Weighted mean of both crops	87	102	107	102	101	(4·5)	..	..	..	..	..	..	..	..
II. SULPHATE OF AMMONIA														
Early Millet and Sorghum														
Manga* 11	54	101	121	88	135	12	2,202	78	83	108	113	119	23	214
Early Millet and Late Millet														
Manga* 9	64	89	135	107	105	24	279	86	82	109	109	114	15	328
Maize and Sorghum														
Damongo 12	91	120	96	104	89	16	293	71	108	102	102	114	15	323
Weighted mean	70	106	114	98	112	9·9	..	79	93	106	108	115	10·4	..
Weighted mean of both crops	75	100	110	103	114	(7·2)	..	..	..	..	..	..	..	..

* Based on weights of unthreshed heads.

The details of the trials are as follows:

Design: four randomized blocks each containing ten plots; plot size $\frac{1}{40}$ acre.

Treatments: Control.
Broadcast shortly before planting.
Placed application to early crop.
Placed application to late crop.
Placed application divided equally between crops.
For the last three treatments the fertilizer was placed with a spoon about 2 in. from the seedling, 20 days after germination. Each treatment was at two levels of fertilizer, 60 and 120 lb. per acre; thus, with two controls there were ten treatments in all. The two different crops were planted alternately down the row.

Experimental Results.—The results for the early and late maturing crops are shown separately in Table 3. The mean yield of each crop has been reduced to 100 so that the result of each trial is given equal weight provided its standard error is not too high. However, as there was a high error in some of the trials the procedure for calculating the semi-weighted mean, described in the last section, was followed, all trials with a standard error for differences between treatments of 15 per cent. or under being given equal weight. Once again, there was little difference between the yields with the high and low rates of application, and in the table the figures are the average for both rates. The weighted means of the treatments on the early and late crops have been averaged to give a mean for the treatments over both crops. The standard error for the differences between this set of treatment means is bracketed, because the variances of the treatment means for the early and late crops from which it is derived are not entirely independent.

In the trials with superphosphate, differences between the four treatments were not significant by the F test either on the early or late maturing crops. For the early crop broadcasting was considerably better than application to the late crop, but for the late maturing crop it was the poorest treatment, possibly because the better grown early crop checked the growth of the later one. If the average for both crops is taken there is little to choose between any of the treatments.

The results of this series support the conclusion derived from the first series, that on these sandy soils placement is certainly no better than broadcasting.

In the trials with sulphate of ammonia differences between the four treatments were not significant by the F test on either the early crop or the late crop, though on the late crop the broadcast application was less effective than the other treatments. This may be due to the earlier application of the broadcast fertilizer, since the late-maturing cereals are known to respond best to delayed applications of nitrogen [1].

In both the superphosphate and sulphate of ammonia trials, the early crop did better if the fertilizer was applied direct to it rather than to the late crop, and the effect of the split application was intermediate; but it made no difference to the late crop which one received the fertilizer.

TABLE 4. *Residual Effects of Sulphate of Ammonia and Superphosphate*

(Single dressing = 1 cwt. per acre, double dressing = 2 cwt. per acre)

Site	Crop	Direct effects (per cent.)					Residual effects (per cent.)										
							First year						Second year				
		N_1	N_2	P_1	P_2	S.E.		N_1	N_2	P_1	P_2	S.E.		N_1	N_2	P_1	P_2	S.E.
Tono 5	Sorghum	2	17	42‡	82‡	12	Early millet and sorghum	34	4	34	78‡	20						
Manga 3	,,	13	49‡	21	16	12	Early millet and late millet	6	36	0	−8	18	Groundnuts	13	10	18	21	10
Damongo 5	,,	17	36‡	12	30†	10	Groundnuts	5	−6	8	18	13	Sorghum	9	17†	13	15†	6
Tamale 7	,,	20	22	−16	7	12	,,	3	1	1	16	10	,,	16	19	−3	10	17
Tono 3	Late millet	22†	29†	4	10	9	Early millet and late millet	10	10	15	19	14						
Zuarungu 4	,,	17†	30‡	7	26†	7	Groundnuts	−5	−3	15	22†	8						
Tamale 6	Maize	8	13	25†	23†	8	Maize and sorghum	12	3	11	11	12	Groundnuts	5	3	18	10	10
Nyankpala 12	,,	11†	22‡	14†	20†	5	Groundnuts	13	13	14	5	11						
Damongo 4	,,	59‡	92‡	9	10	7	,,	−21	−2	−2	−2	15						
Yendi 5	Yams	13	−20	24	22	25	Maize and sorghum	4	6	7	11	7						
Nyankpala 11	,,	10	19†	0	12	8	,,	8	−10	−17	−12	16						
Damongo 3	,,	0	−2	−12	−9	10	,,	8	3	16	11	8	Groundnuts	13	19	21	16	10
Ejura 7	,,	0	14	9	11	6	Maize	−12	−8	56†	40	20						
Manga 5	Groundnuts	−5	−2	25‡	27‡	4	Early millet and sorghum	5	27‡	41‡	50‡	9						
Zuarungu 5	,,	−8	−18†	−1	3	4	,,	13	13	23	37†	13						
Tamale 9	,,	3	−6	−2	−1	6	Maize and sorghum	10	6	18	15	10	Late millet	6	22	19	50†	20
Yendi 9	,,	−14	−31	8	−3	10	,,	2	−8	1	7	7						
Nyankpala 15	,,	−9	0	12	12	7	,,	1	13	29†	51‡	13	Yams	1	−10	−13	−3	10
Damongo 7	,,	6	4	26‡	29‡	6	,,	1	1	14†	9	5	Sorghum	−12	−26	−6	20	26
Ejura 6	,,	−11	−4	−1	−15	10	Maize	30	11	−51†	15	19						
Tono 4	,,	−5	1	11†	11†	5	Groundnuts	4	4	9	15†	6						
Weighted Means	Cereals and yams (13 trials)	15‡	28‡	9†	19‡	3·5	Cereals and yams (15 trials)	7†	7†	15‡	20‡	2·7	Cereals and yams (5 trials)	6	5	1	12	6·1
	Groundnuts (8 trials)	−5	−7	10†	8†	3·4	Groundnuts (6 trials)	1	2	8	14†	4·6	Groundnuts (3 trials)	10	11	19†	16†	6·7
	All crops (21 trials)	6†	14‡	10‡	14‡	2·5	All crops (21 trials)	5	5	13‡	18‡	2·6	All crops (8 trials)	8	8	10†	14†	4·7

† Sig. at 5 per cent. ‡ Sig. at 1 per cent.

III. *Residual Effects of Sulphate of Ammonia and Superphosphate*

In 1949 a series of trials with different levels of sulphate of ammonia and superphosphate were carried out in the savannah areas of the country [1]. The details of these trials were as follows:

Design: 3^3 Factorial, with single replication, divided into three blocks, confounding high-order interactions.

Treatments: Sulphate of ammonia—0, 1, 2 cwt. per acre.
Superphosphate—0, 1, 2 cwt. per acre.
On all crops except groundnuts the nitrogen was applied either early, late, or as a split dressing; but this treatment has been ignored in estimating the N and P residual effects.

Most of the 1949 trials were continued in 1950, and some of them in 1951, without further treatments, in order to determine the N and P residual effects.

Greenwood [4] has already given some information about the residual effects of fertilizers in northern Nigeria, on sandy soils similar to those used in this series. He records four experiments with superphosphate, all of which showed large residual effects in the first year after application; and of the two trials continued for a longer period one showed significant effects in the third, and the other in the fourth year after application. He obtained no residual effects with sulphate of ammonia, but in one trial with gypsum there were substantial effects on groundnuts for two years after application.

Experimental results.—In Table 4 the direct effects, and the residual effects in the first and second year after application, are expressed as percentages of the mean yield in each trial. Averages are shown for yams and cereals, for groundnuts, and for all the crops. Groundnuts have been averaged separately because they do not as a rule respond to nitrogen, and also because they respond to the sulphur in the ammonium sulphate and the superphosphate. The standard errors of the trials differ considerably, and the semi-weighted means have been calculated as in the former series of trials recorded in this paper. The results of trials with standard errors for effects of less than 10 per cent. have been given equal weight.

Sulphate of Ammonia.—On cereals and yams there was a significant residual effect in the first year after application. If the average over the two rates of application is taken, the residual effect was 7 per cent. compared with a direct effect of 22 per cent., or just under one-third. In the second year after application the effect was not significant.

On groundnuts the direct effect was negative. In the first year after application there was no effect, but in the second year the positive effects, while not significant, may indicate that the groundnuts were responding to the sulphur in the sulphate of ammonia.

Superphosphate.—On the average of all the crops the residual effect in both the first and second years after application was equal to the direct effect. On cereals and yams the effect declined in the second year after application, but on groundnuts it appeared to increase. Such a high

effect may be due to the fact that the untreated plots have become very exhausted after three years, and in these circumstances small amounts of phosphorus and possibly sulphur give large percentage returns. The high residual effects also suggest that crops may respond well to phosphates which have been well worked into the soil throughout the rooting range. It may also be concluded that phosphate fixation in these soils is very slight.

In assessing the economic value of phosphates the residual effect has previously been conservatively estimated as 50 per cent. of the direct effect [6]. It is now evident that phosphates are even more profitable than they first appeared.

Summary

Three series of experiments have been carried out with nitrogen and phosphorus fertilizers.

In series I, different rates, times, and methods of application, and qualities of phosphates were tried on cereals and groundnuts. Application at planting time was better than 20 days after germination and significantly better than 40 days after germination on cereals. On groundnuts applications at planting time and 20 days after germination were about equal and nearly significantly better than 40 days after germination. Broadcasting was better than planting-line placement and nearly significantly better than seed placement on cereals, but on groundnuts there was little difference between the treatments. Single super, triple super, and ammonium phosphate were equally effective on both cereals and groundnuts.

In series II, superphosphate and sulphate of ammonia were applied to mixtures of an early and late maturing cereal in four ways: broadcast, to the early crop, to the late crop, and as a split application. With superphosphate there was no difference between the methods on the average over both crops, although for the early crop broadcasting was better than a placed application to the late crop, whilst for the late crop the position was reversed. With sulphate of ammonia there was no significant difference between the methods on the average over both crops, though the broadcast application was notably inferior for the late crop, probably because it was applied too early.

In series III, the residual effects of sulphate of ammonia and superphosphate have been tested for 2 years. The residual effect of sulphate of ammonia on cereals and yams was 7 per cent. in the first year and small in the second compared with a direct effect of 22 per cent. On groundnuts, which showed a negative direct effect, an apparent residual effect in the second year was probably due to sulphur. The residual effect of super on cereals and yams was as high as the direct effect in the first year, but fell off in the second. On groundnuts it was equal to the direct effect in the first year and increased in the second.

Acknowledgements

These experiments were carried out jointly by the officers of the Chemistry Division of the Dept. of Agriculture, and the officers of its

experimental stations, and were co-ordinated by Mr. R. K. Djokoto. The author wishes to express his appreciation to all these officers for their good work.

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(*Received 25 June 1953*)

STUDIES ON PERENNIAL WEEDS: THE CONTROL OF HOARY CRESS (*CARDARIA DRABA*) BY CHLORINATED PHENOXYACETIC COMPOUNDS

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Cardaria draba (L.) Desv., known variously as hoary cress, hoary pepperwort, white weed, and white-top, is a deep-rooted perennial plant, native to Europe. It is known as a weed in many countries and occurs in every Australian state. Prior to the discovery of the selective herbicidal properties of chlorinated phenoxyacetic acids, many papers were published concerning the control of *C. draba* and other deep-rooted perennials. It is not intended to review this literature here but, in general, the degree of control exerted by the then known herbicides was unsatisfactory or outweighed by other considerations such as soil sterility and toxicity to animals.

First reports of the toxicity of chlorinated phenoxyacetic acids to deep-rooted perennial plants were based on short-term observations only. However, the compounds were so promising and had so many desirable properties that it was resolved to attempt their evaluation by long-term field studies. The latter were chosen in preference to pot cultures because of the unsatisfactory growth of deep-rooted perennials under restricted conditions of root space.

The work reported here is part of a series of studies commenced in the spring of 1946 in the Wimmera district of Victoria, where *C. draba* makes its most vigorous growth under Australian conditions.

Experimental methods.—The results recorded have been obtained from field experiments of randomized block design with four or five replications.

A range of concentrations of 2-methyl 4-chlorophenoxyacetic acid (MCPA) as the sodium salt was tested and comparisons were made of a number of different chlorinated phenoxyacetic compounds.

All compounds were applied as aqueous solutions or emulsions by means of pneumatic sprayer at a standard volume of 100 imperial gallons per acre. Hence in this paper a 0·1 per cent. concentration of a particular compound is equivalent to 1 lb. of the acid per acre. In comparisons of salts and esters, the salts were applied with and without the solvent and dispersing agents used in preparation of the ester sprays.

In the different experiments the plot size varied from 0·002 to 0·005 acre. Densities were determined by five randomly distributed 2×2 link quadrats per plot; counts were made prior to treatment and thereafter at approximately 6-monthly intervals for 4 years.

Square-root or logarithmic transformations of densities were used in the statistical treatment of the data; for economy of space the standard errors or L.S.D.s are not shown, but significant effects are stated.

[Empire Journ. of Exper. Agric., Vol. 22, No. 86, 1954.]

During the period of the experiments the population of cress rosettes fluctuated markedly; high spring—low autumn densities alternated yearly with low spring—high autumn densities. Both initial and second spray applications were applied when spring populations were high. Because of these density fluctuations the reduction in the rosette counts on treated plots as compared with those on untreated plots, expressed as a percentage and described for brevity as 'percentage kill', was the principal criterion used in assessing the effects of treatments.

Experimental Results

A series of concentrations of MCPA were compared in a randomized block experiment on old cultivation land heavily infested with *C. draba*. The initial treatments, applied in October 1947, when the plants were

TABLE 1. *Effects of a Series of Concentrations of Sodium MCPA, applied to* Cardaria draba *at the Flowering Stage. (Means of four replicates)*

Treatments applied October 1947	*Mean percentage reduction of rosettes in:*		
	April 1948	*September 1949*	*October 1951*
0·1% MCPA .	68·3*	34·6	23·7
0·2% MCPA .	81·7	50·5	28·1
0·3% MCPA .	84·8	57·9	29·0
0·4% MCPA .	70·1*	42·6	17·3
0·5% MCPA .	82·8	54·0	48·0
Rosettes on untreated plots, per sq. link (mean) .	6·88	11·42	5·20
Significance between:	Treated and control $P < 0.001$ MCPA levels $P < 0.05$	Treated and control $P < 0.001$ MCPA levels n.s.	Treated and control $P < 0.001$ MCPA levels n.s.

* Significantly lower than remainder.

just commencing to flower, were 0·0, 0·1, 0·2, 0·3, 0·4, and 0·5 per cent. MCPA as the sodium salt (i.e. 0 to 5 lb. per acre). The results, given in Table 1, show that there was a significant concentration effect in the year following spraying but thereafter the percentage kill was of the same order for all concentrations.

Further treatments were applied in September 1949, 2 years after the original. Each of the original plots was subdivided into six subplots which received 0·0, 0·1, 0·2, 0·3, 0·4, and 0·5 per cent. MCPA. Hence the experiment included plots sprayed in 1947 only, in 1949 only, in both 1947 and 1949, and untreated controls.

Counts made 6 months later showed that the effects of the second treatments were similar, irrespective of the concentration of the original spray. However, the regeneration of *C. draba* showed a curvilinear

response to increasing concentration of the second application; the calculated quadratic regression was $Y = 159{\cdot}6 - 1731{\cdot}43(x - 0{\cdot}3) + 2585{\cdot}71(x^2 - 0{\cdot}11)$, and the quadratic component of the variance was significant at the 0·1 per cent. level. Reference to Fig. 1 shows that no additional kill was achieved by increasing the concentration of the second treatment beyond 0·2–0·3 per cent.

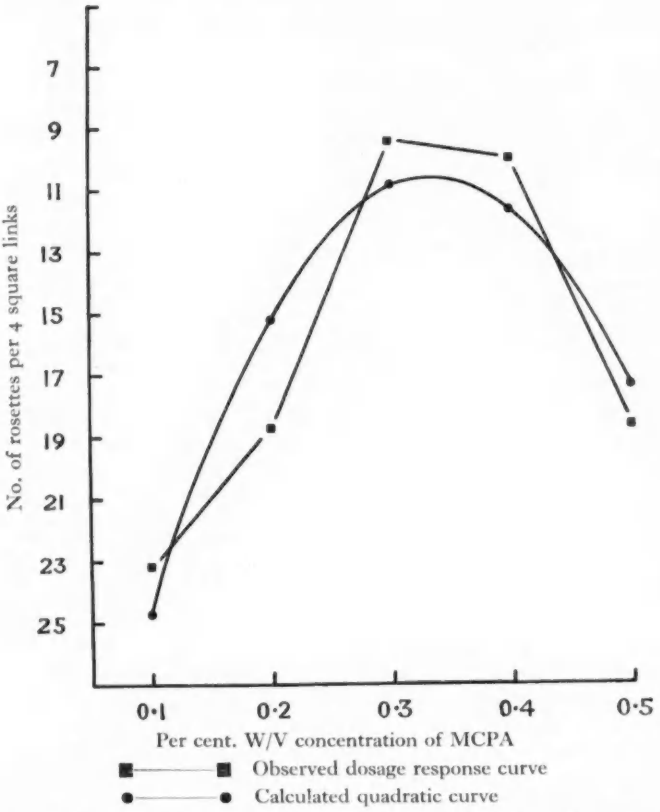

FIG. 1. Effect of increasing concentrations of sodium MCPA on *Cardaria draba* populations (means of 20 sub-plots, 6 months after second treatment).

Comparisons of the effects in 1951 of single sprays in 1947 and 1949 and of resprays in 1949 are made in Table 2. There was no significant effect of concentration 2 years after application of either the first or second sprays. All treatments reduced the population of *C. draba* rosettes but two spray applications gave a higher percentage kill than one.

The relative changes in *C. draba* densities on treated and untreated

plots over a 4-year period are shown in Fig. 2. The figure shows the marked reduction in density during the 6 months following treatment. From this time onward, however, the relationship between plant densities on sprayed and unsprayed plots was remarkably constant. The

TABLE 2. *Comparison of Percentage Kills of* Cardaria draba *resulting from Single and Double Applications of Sodium MCPA. (Means of four replicates)*

	Mean percentage reduction of rosettes in October 1951							
	Initial treatments October 1947							
Second treatments September 1949	*Nil*	*0·1% MCPA*	*0·2% MCPA*	*0·3% MCPA*	*0·4% MCPA*	*0·5% MCPA*	*Sprayed once—1947*	*Sprayed twice—1947 and 1949*
Nil	0 (5·70)	23·7	28·1	29·0	17·3	48·0	29·2 (4·00)	..
0·1% MCPA	27·0	72·1	81·4	67·7	78·3	80·1	..	75·9
0·2% MCPA	29·9	69·7	73·9	81·9	81·4	87·6	..	78·0
0·3% MCPA	40·5	79·9	79·2	91·2	77·9	75·0	..	80·6
0·4% MCPA	50·9	72·3	84·3	90·9	84·7	89·4	..	84·3
0·5% MCPA	53·1	70·1	84·7	88·7	75·2	68·1	..	77·8
Sprayed once—1949	40·3 (3·38)	..	..	..	..	..	..	..
Sprayed twice—1947 and 1949	..	73·2	80·7	84·1	79·5	80·0	..	79·4 (1·16)

Significance between: MCPA levels—n.s.
Sprayed and untreated—$P<0.001$
Sprayed once 1947 and sprayed once 1949—n.s.
Sprayed twice and sprayed once—$P<0.001$

The two right-hand columns and the lowest two rows represent means of the rates shown. Figures in parentheses represent mean numbers of cress rosettes per square link.

seasonal and annual fluctuations in rosette numbers on sprayed plots followed those on the untreated but at a lower density level. Taking the data for the whole 4 years of the experiment, the interaction of percentage kill with time was significant if the counts of April 1948 were included but omitting this date there was no significant interaction.

A comparison of several derivatives of three chlorinated phenoxyacetic acids was made on an area adjacent to the previous experiment. The compounds used were salts and esters of 2,4-dichlorophenoxyacetic acid (2,4-D), sodium 2-methyl, 4-chlorophenoxyacetate (MCPA), and the triethanolamine salt of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). All compounds were used at a concentration of 0·1 per cent. acid equivalent. The treatments were applied in September 1947, when *C. draba* was in the rosette stage of growth. The results, when maximum differences between compounds were apparent, are given in Table 3.

From the table it is seen that all the primary esters of 2,4-D were similar in toxicity and were superior to the two sodium salts. The toxicity of sodium 2,4-D was not increased significantly by the addition of the solvent and dispersing agent used in preparing the ester sprays.

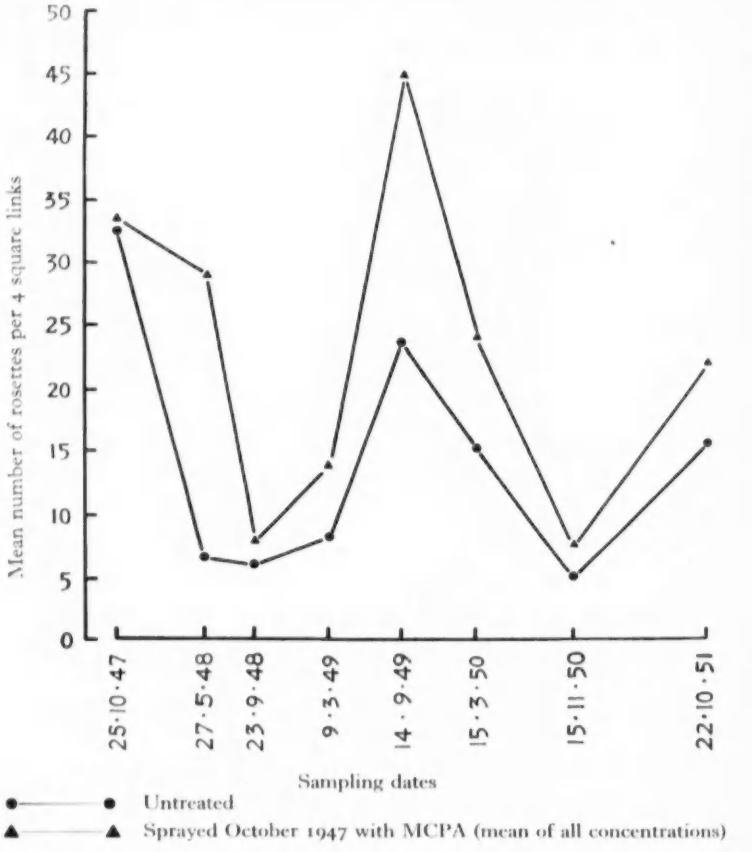

FIG. 2. Fluctuations in the densities of treated and untreated populations of *Cardaria draba* (means of four replicates).

Further comparisons of phenoxyacetic acids were made on *C. draba* at the flowering stage of growth, initial treatments being applied at 0·5 per cent. acid equivalent and second treatments at 0·1 per cent. The compounds used and the results obtained are shown in Table 4.

For 2 years after the original application there were significant compound effects; the order of effectiveness was different, however, from Table 3. In Table 4 it is seen that differences between compounds

gradually disappeared and by 1951 all compounds had effected reductions of a similar order. Moreover, after two applications differences between compounds vanished.

TABLE 3. *Comparison of Different Phenoxyacetic Acid Compounds applied to* Cardaria draba *in the Rosette Stage of Growth. (Means of five replicates)*

Treatments applied September 1947 (0·1 per cent. acid equivalent)	*Mean percentage reduction of rosettes in April 1948*
Sodium MCPA	81·2
Sodium 2,4-D	71·8
Sodium 2,4-D + ester solvent*	76·1
Amine 2,4-D	91·5
Methyl 2,4-D	91·5
Ethyl 2,4-D	91·6
n-propyl 2,4-D	95·1
Butyl 2,4-D	89·7
Amine 2,4,5-T	69·7
Rosettes on untreated plots, per sq. link (mean)	6·59
Significance: > indicates significantly greater reduction at 5 per cent. level	Amine and esters 2,4-D > Na MCPA > Na 2,4-D, amine 2,4,5-T

* 1·0 per cent. lighting kerosene (B.R. 150–250° C.) + 0·1 per cent. Triton B 1956

Discussion

Dosage rates.—Within a period of 6 to 12 months after application there was evidence of a curvilinear response to increasing dosage levels both in the first and second applications of MCPA. The optimum dosage level appeared to be between 0·2 and 0·3 per cent. (Table 1, Fig. 1). At 100 gallons per acre, this is near the figure of 2 lb. per acre suggested by Blackman and Holly [1]. However, in all the Wimmera experiments, significant differences between dosage levels disappeared after 12 months.

The fact that there was an optimum dosage rate for percentage kill in the year following application suggests that maximum downward translocation of MCPA occurred at this level; higher rates presumably because of their more rapid action resulted in poorer translocation.

Comparison of single and double treatments.—Two applications separated by 1 or 2 years effected a greater percentage kill than a single treatment irrespective of the dosage rate of the latter. Reference to Table 2 shows that applications of MCPA at 1 lb. per acre in 1947 and 1949 reduced the density of *C. draba* by 72 per cent. compared with 30 per cent. by a single application of 2 lb. per acre in 1949. In addition, two light applications were as toxic as two heavy ones.

Blackman and Holly [1] also obtained greater percentage kill of *C.*

draba by two sprayings; in their experiments sprays were applied in consecutive years. In the Wimmera experiments a 2-year interval between applications did not appear to reduce the effectiveness of the second spray, for another experiment [2], with a 1-year interval, gave similar results. This is due probably to the relative stability of the *C. draba* population on sprayed plots, in comparison with unsprayed plots, after the first year (Fig. 2). The failure of *C. draba* to reinvade completely the ground previously occupied may be due to the presence of volunteer

TABLE 4. *Comparison of Different Chlorinated Phenoxyacetic Compounds applied to* Cardaria draba *at the Flowering Stage. (Means of four replicates)*

Initial treatments applied 1947 (0·5% acid equivalent)	*Second treatments applied 1949 (0·1% acid equivalent)*	*Mean percentage reduction of rosettes in:*				
		April 1948	*March 1949*	*September 1949*	*March 1950*	*October 1951*
Sodium MCPA	nil	82·8	56·6	54·0	44·0	48·0
Sodium 2,4-D	nil	91·9	66·5	74·9	60·5	35·6
Amine 2,4-D	nil	94·3	72·7	77·2	46·4	34·3
Butyl 2,4-D	nil	82·8	49·2	53·8	44·4	44·5
Sodium MCPA	Sodium MCPA	..	..	..	94·7	80·1
Sodium 2,4-D	Sodium 2,4-D	..	..	..	95·9	87·2
Amine 2,4-D	Amine 2,4-D	..	..	..	89·0	82·3
Butyl 2,4-D	Butyl 2,4-D	..	..	..	93·0	78·8
Rosettes on untreated plots per sq. link (mean)	..	6·88	3·51	11·42	6·11	5·52
Significance: > indicates significantly greater reduction at 5% level	..	2,4-D salts n.s. Amine > ester, Na MCPA	2,4-D salts n.s. Amine > ester, Na MCPA	2,4-D salts n.s. Amine > ester, Na MCPA	Between sprayed twice and sprayed once $P < 0{\cdot}001$. Between compounds n.s.	Sprayed twice and sprayed once $P < 0{\cdot}001$. Between compounds n.s.

Wimmera rye-grass (*Lolium rigidum* Gaud.). Counts taken in 1948 showed that excluding *C. draba*, 80 per cent. of the plants on sprayed plots and 16 per cent. on untreated plots were annual rye-grass. On untreated plots 75 per cent. of the winter annuals were burr medics (*Medicago* spp.) and deadnettle (*Lamium amplexicaule* L.). Evidence from root excavations suggests that rye-grass may prevent the spread of *C. draba* by lateral roots without affecting the seasonal fluctuation of rosette numbers on surviving plants.

The effects of spraying plants previously treated and spraying plants not treated before were compared as follows:

Let A = Mean number of rosettes per square link on untreated plots.
B = Mean number of rosettes per square link on plots sprayed in 1949 only.
C = Mean number of rosettes per square link on plots sprayed in 1947 only.
D = Mean number of rosettes per square link on plots sprayed both in 1947 and 1949.

Then if $\frac{D}{C} = \frac{B}{A}$ or if $AD - BC = 0$, the effect of a spray in 1949 would not be influenced by previous treatment. Using the counts for October 1951 (Table 2), however, it was found that $AD - BC = (5{\cdot}7 \times 1{\cdot}16 - 3{\cdot}38 \times 4{\cdot}00)$. This differs significantly from zero ($P < 0{\cdot}01$) and is negative, hence the effect of a second application was greater than a first. The percentage kill effected by the second application is not simply additive to that resulting from the first. The implication is that plants which have been sprayed before are more susceptible than those treated for the first time.

Root excavations of *C. draba* and other perennial plants indicated that lateral roots and rhizomes are not readily killed by phenoxyacetic compounds. If *C. draba* plants are killed as far as the point of origin of the lateral roots, the latter are induced to form rosettes. The subsequent killing of these rosettes combined with the fact that Wimmera rye-grass may prevent the formation of further lateral roots is a possible explanation of the lesser potential for regrowth following a second treatment. Corns and Frankton [3] also report that grass competition apparently aided the eradication of *C. draba* by phenoxyacetic compounds.

Comparison of compounds.—The autumn regeneration of *C. draba* following an initial treatment the previous spring showed significant compound effects. The differences between compounds persisted for 2 years after application but finally disappeared. Although Tables 3 and 4 are not strictly comparable, the evidence supports the contention of Blackman, Holly, and Roberts [4] that there is an interaction of compound and stage of growth. When applied in the rosette stage of growth sodium MCPA was significantly more toxic than sodium 2,4-D, but at flowering the latter tended to be superior although the difference just failed to reach significance. Triethanolamine 2,4-D was highly toxic at both growth stages and significantly more toxic than the sodium salt in the rosette stage. Esters of 2,4-D were more toxic than sodium MCPA and sodium 2,4-D at the rosette stage but not at flowering.

The disappearance of differences between compounds with time, and the similarity of the effects of compounds after two applications (Table 4), suggest that in so far as the eventual control of *C. draba* is concerned the type of compound is relatively unimportant. A possible exception is 2,4,5-T which was less toxic than 2,4-D when applied as the same salt. However, no data are available regarding the effects of a second application of 2,4,5-T.

The absence of a growth-stage-compound interaction on applying treatments a second time may be associated with the increased susceptibility

of *C. draba* following previous treatment, to which reference has been made previously.

Summary

Experiments conducted between 1946 and 1951 in the Wimmera district of Victoria, Australia, showed that the dosage of sodium 2-methyl, 4-chlorophenoxyacetate (MCPA) for maximum reduction of *C. draba* in the year following treatment was between 2 and 3 lb. acid equivalent per acre. Between 6 and 12 months after treatment, the plants partially recovered, and thereafter the reductions effected by all dosage levels were of the same order.

The recovery following a second application of a phenoxyacetic acid was less than after a single treatment, irrespective of dosage rate. Two applications of sodium MCPA, each at a rate equivalent to 1 lb. of acid per acre, were as effective as two at higher rates and gave a greater kill than a single heavy application. The reduction in density of rosettes 2 years after a second application was more than 70 per cent.

Evidence was obtained that plants which had been sprayed before were more susceptible to chlorinated phenoxyacetic acids than those not treated previously.

Several phenoxyacetic compounds were compared. Differences in toxicities of various compounds were evident for 2 years after an initial application, but such differences disappeared with time. There were no differences between compounds after a second spray application.

Wimmera rye-grass (*Lolium rigidum*) occurred naturally on plots in which the density of *C. draba* had been reduced by phenoxyacetic acid compounds, and the possibility that this grass was a factor in control is discussed.

Acknowledgement.—The author desires to acknowledge the assistance of Mr. G. A. McIntyre in the statistical treatment of the data.

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(*Received 17 July 1953*)

THE JERSEY IN EGYPT

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To meet the increasing demand for better supply of milk in Egypt, some foreign dairy breeds have been introduced during the last twenty-five years. Difficult problems still confront the animal industry in the country, of which one of the more important is that of determining the breeds most suited to Egyptian conditions. Though the one first introduced was the Jersey in 1928, very little is yet known about its suitability. The present paper discusses the first phases of the experiment, i.e. the adaptation and production of pure-bred Jerseys and of Jersey crosses in this country.

Material and procedure.—The material used in this study was obtained through the kindness of the Authorities of the Department of Agriculture of Assiut College (in Upper Egypt), one of the American institutions in Egypt.

In 1928 this College imported four registered Jersey cattle: three cows and a bull from the United States of America. The first concern was to try to increase the milk supply needed for the Mission Hospital and Schools by introducing good germ-plasm into their farm. The pure Jersey was crossed with native cattle to see which of the grades gave the best results under the prevailing conditions. A second importation took place in 1937 from the U.S.A. when three more Jersey cows and a bull were brought to the herd to introduce new blood lines.

The imported foundation stock of cows gave rise to the pure Jerseys in Egypt, whereas the bulls were used on the native cows to produce different Jersey grades i.e. $\frac{1}{2}$, $\frac{3}{4}$, $\frac{7}{8}$, or higher grades of Jersey blood. In this way the cattle have in time differentiated into two groups. One group comprises the pure Jersey from the use of the Jersey bulls on Jersey cows, and the other the Jersey grades resulting from using Jersey bulls on native cattle and then serving the first cross by pure Jersey bulls to obtain higher grades.

Daily records of milk production for both groups offered the material for the present study. The information gathered for this analysis includes all records up to 1950. Incomplete and unusual records were left out and only sound ones were used. As the two groups were kept on the same farm, the environmental differences were minimized.

The use of age correction factors was envisaged and these were calculated separately for the appropriate groups. These factors were arrived at by the paired lactation method devised by Sanders [1].

Results and discussion.—Tables 1, 2, and 3 show the average total yield, the 305 days yield, and the intensity of yield for the pure Jerseys and their crosses with the native cattle. Taking the average production of a well-selected, well-managed group of native cattle to be 3,000 lb.,

[Empire Journ. of Exper. Agric., No. 22, Vol. 86, 1954.]

we find that the Jerseys and the different grades are superior in production to the native cattle. The mean of the three items studied for the F_1 Jersey × native crosses approaches that of the Jersey parents. The same

TABLE 1. *Total Milk Yield*

	Pure Jersey	*15/16 Jersey*	*7/8 Jersey*	*3/4 Jersey*	*1/2 Jersey*
No. of animals	34	2	5	9	15
No. of lactation	155	5	27	29	80
Mean milk yield	5,871 lb.	5,834 lb.	6,321 lb.	5,206 lb.	5,218 lb.
Standard deviation	1,572 ,,	2,565 ,,	2,036 ,,	1,698 ,,	1,334 ,,
Standard error of mean	126 ,,	1,145 ,,	392 ,,	334 ,,	157 ,,

TABLE 2. *305 Days Milk Yield*

	Pure Jersey	*15/16 Jersey*	*7/8 Jersey*	*3/4 Jersey*	*1/2 Jersey*
No. of animals	34	2	5	7	13
No. of lactation	153	5	27	24	70
Mean 305 days	5,594 lb.	5,180 lb.	5,895 lb.	5,195 lb.	5,223 lb.
Standard deviation	1,243 ,,	1,352 ,,	1,729 ,,	1,419 ,,	1,268 ,,
Standard error of mean	101 ,,	604 ,,	333 ,,	290 ,,	152 ,,

TABLE 3. *Intensity (70 Days Yield)*

	Pure Jersey	*15/16 Jersey*	*7/8 Jersey*	*3/4 Jersey*	*1/2 Jersey*
No. of animals	34	2	5	9	15
No. of lactation	167	6	27	29	85
Mean intensity	1,857 lb.	1,727 lb.	1,938 lb.	1,682 lb.	1,786 lb.
Standard deviation	449 ,,	215 ,,	489 ,,	419 ,,	489 ,,
Standard error of mean	35 ,,	88 ,,	94 ,,	78 ,,	53 ,,

figures for Shorthorns arrived at by A. Khishin [2] are close to those for the Jerseys, while the Jerseys exceeded the Friesian production average reported by Sidky [3]. On the other hand the different Jersey crosses had in general a higher production than the corresponding groups of Shorthorn × native or Friesian × native grades mentioned in the two experiments referred to above.

The results obtained for the three breeds and their different crosses with Egyptian cattle may be summarized as follows:

	Blood %							
	100%		*87·5%*		*75%*		*50%*	
Breed	*Lac. no.*	*T.Y.*	*Lac. no.*	*T.Y.*	*Lac. no.*	*T.Y.*	*Lac. no.*	*T.Y.*
Shorthorn	18	5,982	37	4,250	36	5,389	53	4,764
Friesian	26	5,589	12	4,614	21	4,382	38	3,543
Jersey	155	5,871	27	6,321	29	5,206	80	5,218

It can be seen that one Jersey cross equals two top crosses of the Shorthorns and even more than that in the Friesians if used to improve the native cattle by grading up.

Moreover, the fact that the Jerseys were able to survive the hot and dry weather at Assiut (Upper Egypt) during the summer months indicates that they surpass either of the two other breeds in tolerating the heat. This is very important to bear in mind, as the Friesians were kept in the northern part of the Delta (nearer to the Mediterranean), where moderate temperature prevails throughout the summer months; while the Shorthorns were kept about 300 miles north of Assiut. This finding substantiates the views of Badreldin *et al.* [4] that the Jersey rather than the Shorthorn is the breed on which efforts should be concentrated in Egypt. This statement was based on a comparative heat-tolerance test of the ability of Shorthorn, Jersey, native cattle, and buffaloes to withstand the Egyptian summer. Sidky [3] found that the Friesians have great possibilities as far as heat tolerance goes. His heat-tolerance test on different grades shows the good effect of the native cattle blood.

We found a higher yield in the $\frac{7}{8}$ group compared with the pure Jersey group. This may be partly due to an outbreak of foot-and-mouth disease in one season and of epidemic Egyptian fever in two others during the middle thirties, which affected the pure Jerseys at the time and probably for later lactations too. The $\frac{7}{8}$ animals either were not born or were not in milk then.

We measured the ratio between the intensity and total milk yield. This ratio differs among records of the same cow. The mean ratio for the native cow is 0·39 while that for the pure Jerseys is 0·32. The $\frac{1}{2}$ Jerseys, $\frac{3}{4}$, $\frac{7}{8}$, or $\frac{15}{16}$ have the following values: 0·35, 0·33, 0·31, and 0·31 respectively. S. Khishin [5] has shown that the intensity varies from 0·25–0·33 of the total yield. This agrees reasonably well with our present finding with the exception of the native group. The estimate of the native group suggests that most of their milk is produced at an early stage of their lactation (nearly 40 per cent. in 10 weeks). This criterion, together with the shorter lactation period for the Egyptian cattle (which according to Sidky [3] is less than 250 days), suggests that such animals lack the persistency which is an important characteristic for all milk-producing animals.

The average length of lactation of the Jersey animal is longer than that of the Friesians in Egypt and the Jersey crosses, too, surpass the Friesian crosses as shown in the following table:

	Proportion of foreign blood			
	Pure	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{7}{8}$
Friesians . .	275 days	279 days	289 days	283 days
Jerseys . .	323 ,,	290 ,,	298 ,,	324 ,,

Tables 4, 5, and 6 represent the calving interval, length of lactation, and dry period for the pure Jerseys and their crosses. Differences between calving intervals of all groups are not significant at the 5 per cent.

level, while all groups differ significantly in the length of lactation and dry period at the 5 per cent. level. The grades show a tendency towards a longer lactation period than the native cows. Though the numbers involved are small and the difference is not significant, the tendency is for lactation period to increase as the amount of Jersey blood increases.

TABLE 4. *Calving Intervals*

	Pure Jersey	$\frac{15}{16}$ *Jersey*	$\frac{7}{8}$ *Jersey*	$\frac{3}{4}$ *Jersey*	$\frac{1}{2}$ *Jersey*
No. of animals	32	2	5	9	14
No. of lactation	140	7	22	21	70
Mean C.I.	384	413	383	359	363
Standard deviation	71	102	56	28	37
Standard error of the mean	6	40	12	6	4

TABLE 5. *Length of Lactation*

	Pure Jersey	$\frac{15}{16}$ *Jersey*	$\frac{7}{8}$ *Jersey*	$\frac{3}{4}$ *Jersey*	$\frac{1}{2}$ *Jersey*
No. of animals	34	2	5	7	15
No. of lactation	158	8	26	24	75
Mean L.L.	323	341	324	298	290
Standard deviation	76	98	63	43	49
Standard error of the mean	6	35	13	9	6

TABLE 6. *Length of Dry Period*

	Pure Jersey	$\frac{15}{16}$ *Jersey*	$\frac{7}{8}$ *Jersey*	$\frac{3}{4}$ *Jersey*	$\frac{1}{2}$ *Jersey*
No. of animals	31	2	5	6	14
No. of lactation	140	7	22	21	70
Mean length of dry period	65	61	60	67	65
Standard deviation	27	18	15	15	16
Standard error of the mean	2	7	3	3	2

The calving interval estimates suggest that both the pure Jerseys and their grades are regular breeders and give a calf crop almost annually. The $\frac{1}{2}$ Jersey and the $\frac{3}{4}$ Jersey groups have a calving interval 3 weeks shorter than either the pure Jerseys or the $\frac{7}{8}$ Jersey animals. The average calving interval in one herd of Egyptian cattle has been reported by Asker and Ragab [7] to be nearly 422 days. Our finding agrees well with that of Lecky [8], who found that the calving interval of Jerseys in Jamaica did not vary greatly between pure-breds (14·2 months) and the grades (13·8 months).

Age at first calving.—The average age at first calving of Egyptian cattle is not known. Asker and Ragab [7] gave an estimate of 33·2 months, but as it was derived from a limited number of animals kept at the College of Agriculture farm, Giza, it may not represent the estimate for the whole of native cattle in Egypt. It is found that there is a decrease in the average age at first calving for animals of the different crosses as the Jersey blood percentage increases, with the exception of the $\frac{3}{4}$ Jersey group. The average age at calving of 10,069 Jersey heifers found by Turner [9] was 27·3 months. Khishin's material [5] yielded an estimate of 27·95 months. The present data showed an average of 28·4 months for Jersey heifers. It is interesting to note that the Jerseys or their crosses calve at rather an early age in Egypt than they do elsewhere in the tropics. Lecky [8] gives a figure of 35·8 months for Jerseys in Jamaica, and 38·3 months for the Jersey × Zebu cross. No significant effect was found of the age at first calving on yield.

The average age of the population (Jersey and crosses) in terms of times calved was found to be:

3·1 calvings for the pure Jersey,
4·4 „ „ „ $\frac{1}{2}$ Jersey,
4·2 „ „ „ $\frac{3}{4}$ Jersey and over.

This may be compared with the English value of 3·1 [6].

These higher values obtained by us can be explained by the fact that no culling or selection took place for animals in the herd. They were kept as long as they were fit to produce. It is only recently that some landowners started purchasing some Jersey crosses from the American College. Another point is that as there was a greater demand for the higher grades ($\frac{3}{4}$, $\frac{7}{8}$, or more), the animals belonging to these groups had a shorter stay in the herd. The average age of cows at calving was found for the pure Jersey group to be 54·7 months, while that for the $\frac{1}{2}$ Jerseys was 74·1 months and that for the $\frac{3}{4}$ Jerseys and over group was 67·7 months. These experiments would have been more valuable if the effect of back crossing the F_1 Jersey × native animals to their native parents could have been studied, which would allow us to compare groups with $\frac{1}{4}$ Jersey blood, $\frac{1}{8}$ Jersey . . ., &c. Experiments now under way should allow us to find out the performance of such crosses in milk production, heat tolerance, and local-disease resistance.

Relation of age to lactation.—The effect of age in lactations on total yield is summarized in the following table:

Group	*Lactation*				
	1st	*2nd*	*3rd*	*4th*	*5th*
Pure Jersey . .	1·0	1·04	1·08	0·93	1·15
$\frac{3}{4}$ Jersey and over .	1·0	1·03	1·13	1·11	1·17
$\frac{1}{2}$ Jersey . .	1·0	1·07	1·09	1·05	1·04

The maximum yield is reached in the fifth lactation for the pure

Jerseys while the crosses reached their maximum yields in the third lactation with the exception of the $\frac{3}{4}$ or over group. This, however, agrees with the finding of Lecky [8] that the Jersey's performance increased up to 117 per cent. in Jamaica by the third lactation. The Jerseys in Egypt reached the maximum of 115 per cent. in their fifth lactation. Their third lactation performance was only 108 per cent.

In evaluating such an experiment, the study of backcrossing the F_1 animals to the native parents should be taken into account. The intercrossing of the F_1 animals is desirable, too. By crossbreeding and subsequent breeding from within it may be possible to develop a strain better suited to the environment.

From the foregoing, despite the two limitations mentioned, it can be safely concluded that the Jersey can do well in Egypt. Its potential ability in crossing and its hardiness compared with other imported breeds suggests a wider use for the breed and its crosses as a means of increasing the milk supply in the country.

Summary

1. An analysis has been made of the life and calving statistics of a herd of imported Jersey cattle and Jersey × native crosses in Egypt, comprising 65 animals with 296 lactations. The animals with a high percentage of Jersey blood ($\frac{3}{4}$ or over) averaged about 600 lb. of milk more than the $\frac{1}{2}$ Jerseys in the 305-day lactation.

2. The average age at first calving is 28·4, 32·4, 28·9, 26·7, and 27 months for the pure Jerseys, $\frac{1}{2}$, $\frac{3}{4}$, $\frac{7}{8}$, and $\frac{15}{16}$ Jerseys, respectively.

3. The average calving interval is 384 days with a lactation period of 323 days and a dry period of 65 days for the pure Jerseys, with corresponding figures of 363, 290, and 73 for the $\frac{1}{2}$ Jerseys. Jerseys and their crosses have a longer lactation period than Friesians and their grades in Egypt.

4. Under Egyptian conditions grading native cattle to the Jerseys is more beneficial than so doing with Shorthorns or Friesians.

Acknowledgements

The writers wish to take this opportunity to remember with gratitude Mr. M. C. McFeeters, formerly Head of the Agriculture Division, American College, Assiut, for affording the data used in this study.

We wish to mention our colleagues in this Department for help in extracting the information from the original records.

Our thanks are due to Ibrahim University for granting the funds for this research.

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(*Received* 3 *February* 1954)

THE USE OF NITROGEN FOR SUGAR-BEET GROWN ON LIGHT LAND

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BEFORE the war many experiments were carried out, mainly at Rothamsted and the Norfolk Agricultural Station, on the use of nitrogenous fertilizers in sugar-beet cultivation. They showed that the most profitable dressing varied from 3 to 4½ cwt. of nitrate of soda or its equivalent per acre, depending on seasonal conditions and the district in which the crop was grown, and that all this fertilizer could normally be applied to the seed-bed. When growing conditions were very favourable the heavier dressing was often profitable, and on light soils top-dressing after singling was sometimes advantageous.

But some sugar-beet growers on the very light and often 'blowing' soils in Norfolk considered that heavier dressings of nitrogen were essential on these soils, and applied the equivalent of 8 cwt. of nitrate of soda or 6 cwt. of sulphate of ammonia per acre. Most of this fertilizer went on to the seed-bed, but often about 1½ cwt. of sulphate of ammonia was given as a top-dressing after singling. The need for these heavy applications was tested in an experiment begun at Heacham in north-west Norfolk in 1950 and repeated in 1951 and 1952, on a light, stony, sandy soil. The average annual rainfall at Hunstanton, some 3 miles from the site of the experiments, is about 25 inches.

Each year the experiment was based on a 5×5 Latin square design. In 1950 the treatments were 0, 2, 4, 6, and 8 cwt. of sulphate of ammonia per acre and in 1951 and 1952 they were 0, 3, 4½, 6, and 7½ cwt. per acre. All the nitrogen was applied to the seed-bed before drilling except for the plots receiving the heaviest dressing, where 6 cwt. was given in the seed-bed and the remainder as a top-dressing just after singling. Each year a basal dressing of 4 to 5 cwt. of superphosphate and 2 cwt. of muriate of potash per acre was applied, and in 1950 and 1951 5 cwt. of salt per acre was also given on all plots. No dung or ploughed-in straw was used. The experiment was drilled about the third week in March and was harvested in early October in 1950 and in early December in 1951 and 1952.

The results of the three years' work are given in Table 1. Noxious nitrogen determinations were made in 1951 and 1952 by comparing (in a colorimeter) the intensity of the colour of a water extract plus Stanek–Pavlaf solution with that of a standard solution. In all the experiments the number of plants per acre was about 25,000 and was unaffected by treatment.

Yield of clean beet.—Each year there was a marked response to sulphate of ammonia, and from the mean of all 3 years 4½ cwt. of sulphate of ammonia per acre gave the highest yield, but the results of the individual years varied greatly. In 1950 4 cwt. of sulphate of ammonia increased

[Empire Journ. of Exper. Agric., Vol. 22, No. 86, 1954.]

TABLE 1. *Effects of Nitrogenous Manuring*

Treatment, 1951 and 1952 (1950 in brackets)	*Yield of clean beet tons per acre*				*Sugar %*				*Yield of sugar cwt. per acre*				*Noxious nitrogen mg. %*			*Yield of tops tons/acre*
	1950	*1951*	*1952*	*Mean*	*1950*	*1951*	*1952*	*Mean*	*1950*	*1951*	*1952*	*Mean*	*1951*	*1952*	*Mean*	*1952*
No nitrogen . .	10·9	12·3	10·3	11·2	15·9	18·3	18·4	17·5	34·8	45·0	37·8	39·2	18	29	24	4·5
3 (2) cwt. S/A per acre .	13·1	15·1	12·9	13·7	16·1	18·3	18·5	17·6	42·1	55·2	47·8	48·4	15	36	25	5·9
4½ (4) cwt. S/A per acre .	14·7	15·7	12·4	14·3	15·8	18·2	18·2	17·4	46·5	57·2	45·3	49·7	33	41	37	6·9
6 cwt. S/A per acre . .	14·6	16·0	11·8	14·1	16·0	17·9	17·9	17·3	46·8	57·5	42·4	48·9	31	49	40	7·0
7½ (8) cwt. S/A per acre .	14·8	16·7	10·8	14·1	15·8	17·4	17·2	16·8	47·0	58·3	37·1	47·5	29	52	40	7·7
L.S.D.	0·8	1·3	1·6	..	N.S.	0·4	0·6	..	2·7	4·6	7·1	..	..	6·5	..	0·6

TABLE 2. *Rainfall at Hunstanton*

Year	*Total 1 Sept. to 1 Mar.*	*Total March to Sept.*	*Total for 13 months 1 Sept. to 1 Oct.*
1949–50	11·70	14·46	26·16
1950–1	13·41	15·79	29·20
1951–2	10·71	11·44	22·15

the yield by 3·8 tons of clean beet per acre over the control plots, but fertilizer in excess of this amount had no effect on yield. The response of the crop to nitrogen was greatest in 1951 and each increase in the level of fertilizing increased the yield of clean beet. The first 3 cwt. of sulphate of ammonia increased the yield by 2·8 tons per acre over the control and the next 4½ cwt. of sulphate of ammonia gave a further 1·6 tons of clean beet per acre. Both these differences were statistically significant. In this year the total increase in yield of 4·4 tons per acre was the greatest recorded in these experiments. Growing conditions in 1952 were in marked contrast to those in previous years and the maximum response of 2·6 tons per acre was much lower than in any other year. This was obtained from 3 cwt. of sulphate of ammonia which gave about the same increase as in 1951. In 1952, however, nitrogen in excess of 3 cwt. of sulphate of ammonia per acre was harmful to the crop and the extra 4½ cwt. of sulphate of ammonia on the 7½ cwt. plots reduced the yield by 2·1 tons per acre.

Sugar percentage and yield of sugar.—In 1950 the sugar content of the roots was unaffected by the level of manuring and so the yields of sugar followed closely those of clean beet, but in the other years the heavier dressings of sulphate of ammonia reduced the sugar content of the beet. In 1951 the reduced sugar content on the more heavily fertilized plots was more than counterbalanced by the increased yield of roots, but in 1952, when both yield of roots and sugar content were reduced by heavy manuring, the plots receiving 3 cwt. of sulphate of ammonia per acre gave the heaviest yield of sugar. It seems that in most years 3 cwt. of sulphate of ammonia per acre gives the highest sugar content, but that owing to the increased yield of roots from an additional 1½ cwt. of fertilizer, 4½ cwt. per acre gives the highest yields of sugar.

Juice purity and yield of tops.—The effect of the treatments on the noxious nitrogen content of the roots was measured in the two contrasting seasons 1951 and 1952. Noxious nitrogen is a term applied to nitrogen compounds present in the juice of sugar-beet which prevent the crystallization of the sugar during processing in the factory, and so reduce the amount of sugar obtained from each ton of roots. In these experiments the level of noxious nitrogen in the roots was much higher in the dry 1952 season than in 1951, a wetter year, and also the effect of the different levels of nitrogenous fertilizer differed between the two years. In both years the noxious nitrogen content was greatly increased by the use of sulphate of ammonia, but whereas in 1951 it reached its peak with 4½ cwt. per acre and was not further affected by heavier dressings, in 1952 it continued to rise as the amount of fertilizer applied was increased. Thus not only did the two higher levels of sulphate of ammonia reduce the yield of roots and their sugar content in 1952, but also by increasing the amount of noxious nitrogen in the roots, they led to a further loss of sugar at the factory.

It appears that the use of nitrogenous fertilizers inevitably leads to some increase in the noxious nitrogen content of the roots, but, provided the fertilizers are used wisely, their harmful effects are offset by the increased yields of roots so obtained. The 1952 results, however,

emphasize the danger of using more than 4½ cwt. of sulphate of ammonia per acre.

Yield of tops.—The yield of tops was measured in 1952 when growth was limited by the lack of water. Even in that year, however, there was a definite but small response from up to 4½ cwt. of sulphate of ammonia. There was no further increase in yield of tops from 6 cwt. of sulphate of ammonia, but 7½ cwt. gave an additional 14 cwt. per acre. The last 1½ cwt. on the 7½-cwt. plots were given as a top-dressing after singling, and it is possible that this late application of nitrogen, although it had no effect on the yield of roots, stimulated the growth of tops.

Discussion

The response of a crop to fertilizer depends on many factors, including the physical condition of the soil, the weather during the growing season, the supply of other plant nutrients, and the attacks of pests and diseases. In this series of experiments the soil type and standard of cultivation were similar in all years. The date of harvesting was earlier in 1950 than in 1951 or 1952 but this is unlikely to have affected the relative responses to different treatments. All plots received ample supplies of phosphate and potash and there were no symptoms of mineral deficiency on any plot. Attacks by pests were never serious and the severity of virus yellows infection did not vary greatly from year to year. The variation in nitrogen response between years therefore probably depends on differences in the weather conditions.

If no other factor limits growth, the response of a crop to nitrogen depends on the amount of moisture available to the growing crop and the amount of available nitrogen in the soil before the fertilizer is applied. These two factors are influenced by the rainfall during the growing season and the previous winter. If the winter has been wet and much leaching has taken place the soil will probably be low in nitrate and the following crop will respond markedly to nitrogenous fertilizer. Leaching will normally be more severe on the lighter classes of soil, as used in these experiments. The amount of water available to the growing crop depends primarily on the spring and summer rainfall but is also affected by the evaporation rate. The local rainfall figures for the period of these experiments are given in Table 2.

In 1950 the rainfall during the previous winter was about average, and despite a rather dry March, sufficient rain fell after drilling for the beet to grow steadily without serious check. The winter 1950–1 was very wet, presumably leading to heavy loss of soil nitrogen by leaching, and abundant rain fell during the 1951 growing season. These two factors probably explain the marked response to sulphate of ammonia recorded in 1951 and also the high average yield of roots during that year. But heavy rains fell during March, April, and May 1951 and these may have leached out some of the treatment fertilizer and lowered the effective levels of manuring. The high yields from the control plots in 1951 are difficult to interpret although they may have been due to the excellent growing conditions during spring and summer. In contrast the 1952

season followed a winter with below-average rainfall and was itself rather dry, with many hot dry days during the summer when evaporation rate was high and the beet flagged badly. These dry conditions were probably responsible for the low average yield of roots, the poor response to nitrogen, and the toxic effects of heavy dressings of sulphate of ammonia in this year.

The optimum dressing of nitrogen for sugar-beet on these sandy soils in Norfolk evidently varies from year to year and is probably related to the rainfall during the growing season and the previous winter. The results suggest that if winter rainfall is normal the optimum dressing varies from 3 to 4½ cwt. of sulphate of ammonia per acre, depending on summer rainfall. If ample rain falls during the growing season the crop will give an economic response to the heavier dressing, but if the summer is dry 3 cwt. per acre will be sufficient. As it is impossible to forecast the rainfall during the growing season at the time when fertilizers are applied in the early spring, the best policy on these soils is to use, in addition to phosphate and potash, 4 to 4½ cwt. of sulphate of ammonia per acre or its equivalent in the form of other fertilizers. If the previous winter has been very wet, a further 1½ cwt. of sulphate of ammonia per acre may be necessary to counteract the effect of leaching.

Summary

1. In experiments in 1950, 1951, and 1952 on sugar-beet grown on light land in Norfolk, the average yield of roots increased with applications of sulphate of ammonia up to 4½ cwt. per acre but there was no further increase from heavier dressings. The responses to nitrogen varied between years in a way that appears to be related to the seasonal rainfall. The results do not support the view that sugar-beet grown on these light soils requires more nitrogenous fertilizer than on heavier soils.

2. More than 3 cwt. of sulphate of ammonia per acre caused a reduction in the sugar content of the roots, which was most marked in a dry season, but the highest average yield of sugar was given by 4½ cwt. of sulphate of ammonia per acre.

3. Noxious nitrogen content of the roots was lower in the wetter of the two years when it was determined, and was increased by the use of nitrogenous fertilizer.

(*Received 16 December 1953; as amended, 10 March 1954*)

THE ORIGINS OF INFESTATIONS OF COCOA BY TOBACCO BEETLE IN NIGERIA

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THE tobacco beetle (*Lasioderma serricorne* Fabr.) has been known in Nigeria since 1930 and its economic importance has been recognized by the Nigerian Tobacco Company at Ibadan for many years. It has also caused considerable concern by damaging stored cocoa. From 1944 to 1947 the evacuation of cocoa was delayed from certain growing areas and collecting centres in the Western Provinces and prolonged storage led to an increase in infestation necessitating destruction of several thousand sacks. At that time infestations on cocoa appeared to be localized, but in 1951 a detailed series of records confirmed the later impression that the insect was liable to be present on cocoa in any part of the growing areas. Earliest reports in the season came in November from evacuation ports on the river Niger, while the greatest incidence usually occurred during the driest months of February and March. Harvesting of the main crop commences in October when the heavy rains have finished and is usually completed by January or February. Evacuation is normally completed soon after April before heavy rains recommence.

The insect at present causes very little physical damage to cocoa but now that it has become more widespread the potential danger has increased and will become real if long storage is unavoidable. An *ad hoc* field survey was therefore started in November 1951 to investigate the origin of the beetles in cocoa, their distribution and alternative hosts. Previously no specific investigation had been made on this subject and the total information available was very scanty.

Previous records.—All the early references to *L. serricorne* in Nigeria were by Golding, who noted that it was first found on stored cocoa at Ibadan in 1930. Further observations [1] indicated that the insect was only associated with cocoa that had been in store for a long time and had dried to a moisture content of 6 per cent. or lower. He recorded it also on imported carrot seed, stored ginger, cigarettes, and cigars [2]. Details are not given in this publication of the places and time of year of the infestations. Elsewhere Golding [3] reported that bales of tobacco from northern Nigeria were frequently seriously infested with *L. serricorne*, and that the insect had been a serious pest at the Nigerian Tobacco Factory at Ibadan since 1935.

Howe [4] caught isolated flying specimens of the insect in Kano in 1949 but they were not recorded as being associated with any particular produce.

Observations in southern Nigeria.—Tours of inspection of the Western Provinces in November 1951 and October and November 1952 revealed

[Empire Journ. of Exper. Agric., Vol. 22, No. 86, 1954.]

that cowpeas, imported into the area from the north by rail and from the east by the river Benue, were the most important host of Lasioderma. Infestations were heaviest at such key-points as Lokoja where comparatively large stocks were being held by traders in anticipation of rising prices in December. The insect was also recorded occasionally on locust beans (which are produced in the cowpea-growing areas and follow the cowpea trade routes) and on cocoa, tobacco leaf, cassava starch, soya beans, shea nuts, sunflower seeds, and butter beans. It has not yet been recorded on stocks of locally grown cowpeas, nor on the numerous other items of food commonly seen in Yoruba markets, which include dried fish, dried meat, chillies, groundnuts, rice, kola nuts, castor seeds, benniseed, dried plantain, *gari* (a preparation of cassava), maize, guinea corn, melon seeds, tamarind, and cotton seeds.

In general, the insect was widely distributed throughout the Western Provinces, and liable to become prevalent wherever there were suitable breeding grounds provided by stored commodities, particularly imported cowpeas. A complete neglect of storage hygiene by local traders was responsible for the general high level of infestation of these commodities. Produce for export, such as cocoa, was invariably kept under excellent conditions and was by comparison very lightly infested. The unpalatability of cocoa to Lasioderma may have been another reason for its light infestation.

Observations in northern Nigeria.—In February 1951, during severe Harmattan conditions, dead adults of *L. serricorne* were found by the author on locust beans in Kano. In October 1951 several lots of insect specimens were received from R. Willoughby in Kano. All proved to be *L. serriocorne* and they were said to be actively infesting bagged locust beans and cowpeas being stored in the Sabon Gari market at Kano. A further infestation was recorded shortly afterwards in the Kano Railway goods shed on bagged cowpeas from Maiduguri, in extreme north-east Nigeria.

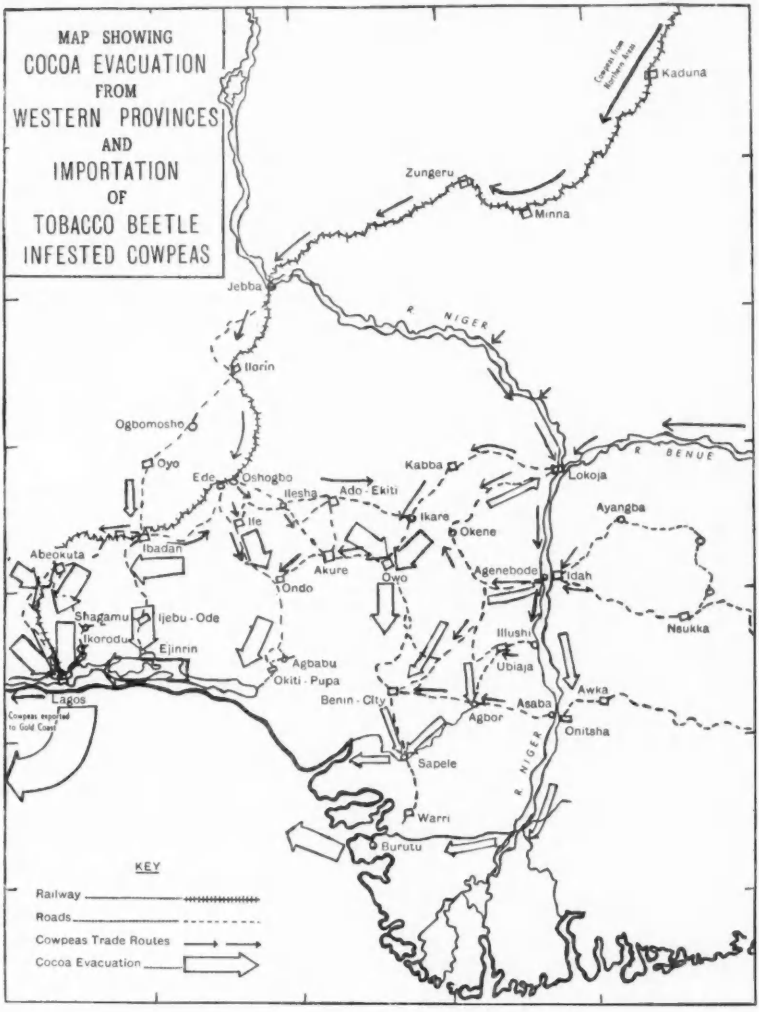
On 15 November 1952 Lasioderma was numerous and active on cowpeas at Nguru (150 miles north-east of Kano) although the Harmattan was fairly severe (at 7 a.m. R.H. was 24 per cent. and shade temp. 17° C.; at 4 p.m. R.H. was 12 per cent. and shade temp. 31·5° C.). Also in November 1952 similar heavy infestations were observed on cowpeas at the more southerly towns of Ringim and Kano, where humidities were slightly higher.

Continuous observations have recently been kept on one store in Kano containing 150 tons of cowpeas from Garrin Gabbas (80 miles north-east of Kano). The cowpeas have remained actively and heavily infested with Lasioderma since first observed on 11 February 1953 until the present time (June 1953).

All the cowpeas and locust beans referred to above were destined to be railed to the Southern Provinces.

Climatic preferences of L. serricorne.—Data obtained from daily records of Lasioderma killed at the Nigerian Tobacco Company at Ibadan during the last five years have shown regular marked seasonal fluctuation of insect numbers. The most consistent feature of these records was the

almost complete absence of insects during the months of June, July, and August. No explanation has yet been found to account for this and it is possible that the effect may be connected with the fact that these



are the three wettest months and have the highest prevailing relative humidities, averaging 80–90 per cent. Lasioderma is seldom recorded on cocoa during these months, except sometimes in June on unevacuated residual main crop. The cocoa in store during these three months is usually light-crop cocoa which is evacuated very quickly and does not

have a chance to show much infestation. There is thus little or no evidence on the question whether the insect will breed on cocoa during the wet season.

At Lagos, where humidity is consistently very high, it is a common observation that the beetles are only active on bright sunny days. Whether or not this is due to a lowering of humidity is not known. In this connexion the observation of Runner [5] in the U.S.A. that the insect did not thrive at relative humidities of 90 per cent. and over owing to fungal attack is of interest.

At the other extreme it is apparent that the insect is capable of surviving Harmattan conditions in northern Nigeria: viz. humidities of 10–20 per cent. and sometimes lower, and wide diurnal temperature variations such as are quoted in the previous section. These observations were unexpected because according to Powell [6] development below 45 per cent. relative humidity is impossible and the insect is not known to have a resting stage. The microclimates in the vicinity of Lasioderma breeding on different foodstuffs and under various conditions is a subject of future study.

Discussion.—More work requires to be done on the attractiveness of cocoa of various moisture contents in view of Golding's observation that only cocoa of moisture content of 6 per cent. and lower is attractive to Lasioderma.

Numerous instances were recorded during the surveys in 1951 and 1952 when cocoa for export was being kept within a few feet of Lasioderma-infested cowpeas and it would appear that a great deal of the infestation of cocoa in Nigeria takes place by cross infestation from this commodity. The Lasioderma-infested cowpeas are grown in the Northern Provinces and railed to Ibadan and nearby stations for distribution into the western side of the Western Provinces. They are also grown in the hinterland of the Benue and sent by river to Lokoja and other Niger ports for supplying the needs of cocoa farmers in the eastern side of the Western Provinces. The appended map shows how cowpeas conveyed by local trade routes may come into the vicinity of cocoa for export. Quantitative data are now being collected on the cowpea trade in order to assist in assessing the importance of this commodity as a carrier of Lasioderma to the cocoa crop.

The importation of cowpeas and other foods into the Western Provinces of Nigeria from the surrounding territories on a large scale is of recent origin and has resulted from the disturbance of the domestic economy of the Yoruba farmers. As a result of their increased wealth due to cocoa production they can afford to import relatively expensive foods and to dispense with working their own farms for supplies.

Acknowledgement.—Identities of insect specimens in 1951 and early 1952 were kindly confirmed by J. G. R. Sutherland.

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(*Received 9 February 1954*)

TWO SOIL TESTS FOR CULTIVATION INVESTIGATIONS

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THE determination of aggregate size and volume weight are still the most widely used tests for comparing the effects of cultivation implements. Keen's technique [1] of aggregate analysis by sieving the soil at field moisture content has been used in many experiments [2, 3], and has proved to be a useful method for comparing the comminution produced by different implements. The method does, however, suffer from three disadvantages [4]:

1. It involves hard manual work.
2. It causes comminution of the soil itself.
3. Different operators obtain different results.

The measurement of the volume weight of loose cultivated soils (sometimes as low as 0·6) has generally been carried out in the past by various core-cutter methods. Such methods are of little use in many British soils because of stones and compaction of the soil within the cutter. Moreover, even in stone-free soil, it is difficult to find a simple way of closing the bottom of the cutter before it is removed from the soil. The sand bottle method [5] cannot be used in cultivated soils because sand is apt to run out of the sample hole down fissures. For their own work the authors have now discarded both these techniques in favour of a crude excavation method which, although tedious, has proved feasible in very loose and in stony soils.

The Mechanical Aggregate Analyser

Mechanizing the sieving process has been suggested as a means of reducing the three disadvantages set out above [6]. The high-frequency type of vibrator now commonly used in industry provides a particularly satisfactory method of shaking sieves for aggregate analysis, and an apparatus making use of this principle has been built at the National Institute of Agricultural Engineering.

Perforated metal sieves were used in preference to woven wire ones on account of their greater mechanical strength and less abrasive surface. The present nest consists of the following 18-in. diameter sieves: 1½ in. and ½ in. square holes and ¼ in. and ⅛ in. round holes. When implements which produce a large quantity of dust are being studied, it would appear desirable to have an extra sieve with holes smaller than ⅛ in. The sieves are carried in a massive steel frame, on sponge rubber pads, as shown in Plate 4, Fig. 1. The rings carrying the sieves swing out, like the sections of a multi-lens magnifying glass, so that the soil can be easily tipped out for weighing. Each sieve carries on its side a 1/30th h.p. series-wound electric motor mounted with its shaft vertical. The lower

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end of the shaft is extended to carry an eccentric weight which is level with the sieve mesh. The motor drives the weight at approximately 3,000 r.p.m. and a small-amplitude vibration of an equivalent frequency is thus imparted to the sieve. The weight of each sieve and motor is approximately 6 kg. and a weight equivalent to 0·73 kg. at a distance of 1 cm. from the centre of the shaft has been found to cause satisfactory soil movement with the minimum of aggregate break down. The period of agitation is standardized at $\frac{1}{2}$ minute for most experiments. Samples up to 5 kg. can be handled. The apparatus is found to be at least as gentle as the *most careful* hand sieving, yet quite effective in causing the soil to pass through to the appropriate sieve.

The results of one experiment to test the gentleness of the apparatus are given in Table 1, which shows the values obtained for the aggregate distribution in a sandy loam by machine sieving, and by hand sieving with far more care than would be practicable in routine work.

TABLE 1. *Comparison of Hand and Machine Sieving*

Percentage of aggregates within fraction. (Mean of 10 samples)	$> 1\frac{1}{2}$ in.	$< 1\frac{1}{2} > \frac{1}{2}$ in.	$< \frac{1}{2} > \frac{1}{4}$ in.	$< \frac{1}{4} > \frac{1}{8}$ in.	$< \frac{1}{8}$ in.
Hand sieving . .	16·0±3·6	41·6±4·0	19·2±2·3	11·5±1·9	11·7±1·8
Machine sieving .	15·1±3·6	42·9±6·7	21·4±3·3	11·3±2·0	9·4±2·2

The ± values represent the 95% confidence limits.

Determination of Volume Weight by Excavation

The technique depends upon removing and weighing a very large volume of soil so that boundary errors, which would be very serious with a sample of conventional size, may be assumed unimportant. In practice an area of 3 ft. square has been found large enough to justify this assumption. The depth to which the excavation is carried out must, of course, depend upon the purpose for which the measurement is made, but, as the accuracy with which the sides can be cut is greater than that for the top and bottom, it should not be less than 4 in. The main item in the apparatus is a square wooden frame with a spike, which projects a few inches, fitted at each corner (Plate 4, Fig. 2).

To carry out a determination the site is roughly levelled and the spikes of the frame pressed firmly into the ground. With the help of a straight-edge the entire area thus enclosed is levelled to conform with the bottom edge of the frame and the soil removed is discarded. Since it is usually impossible to break aggregates in this levelling process some discretion must be exercised in removing aggregates which will leave depressions below the desired surface, and in leaving aggregates which project slightly above the surface. The soil within the frame is now removed to the required depth and weighed. The procedure for doing this is as follows. A strip of soil is carefully scooped out from along one side, using a board cut to the required dimensions as a depth gauge, and work-

ing from the underside of the frame as the upper reference level, as shown in Fig. 2. The remainder of the sample area is now dug out to within 1 in. of its full depth with a spade, and, working across a few inches at a time from the strip already scooped out, is carefully levelled to the full depth required, again using discretion over projecting clods. Finally, the sides are trimmed with a pointing trowel, and all the soil which has been removed from inside the frame is weighed.

TABLE 2. *Dry Volume Weight of Sandy Loam by Two Methods*

	Mean volume weight of 10 samples	
Core-cutter method . .	0·80	±0·08
Excavation method . .	0·81	±0·07

The ± values represent the 95% confidence limits.

The method has been found to give tolerably reproducible results even in very stony soils. In Table 2 the results of an experiment using a 3×3 ft. square frame and working to 4 in. depth are compared with those obtained from a more conventional 6×6×4 in. square core-cutter working on a stone-free, highly organic, sandy loam, which suffered little compaction in the cutter. It will be seen that, under these ideal conditions for the conventional instrument, both the mean and the scatter of the readings by the two methods were very close.

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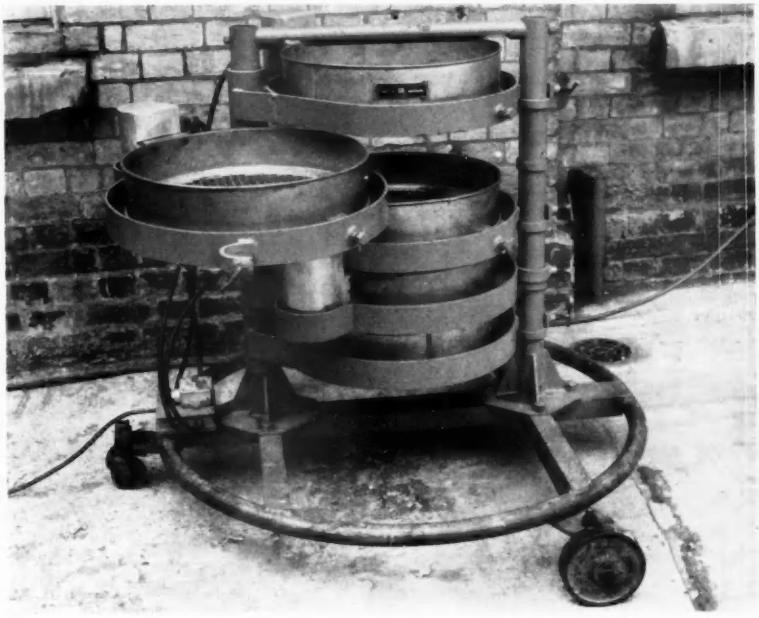

FIG. 1. The mechanical aggregate analyser

FIG. 2. Determination of volume weight by excavation

STUDIES ON THE GROWTH OF CLUN LAMBS

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EWES and lambs will provide a very great increase in liveweight gain per acre during the spring and early summer, the growth rate of the lamb being extremely rapid, particularly in the first 3 months of its life. Before carrying out critical experiments on lamb production and carcass quality, preliminary investigations were made into the technique of measuring the growth rate of lambs in terms of liveweight gain and increase of skeletal size. In addition the growth rate of twins and singles and of ewe lambs and wether lambs was compared. The present paper deals with the results obtained during the 1953 season at Drayton.

A flock of 40 Clun ewes was tupped in October–November 1952, using a Clun ram. Lambing commenced in the first week of March and 65 lambs were born. Records were kept of 54 of these, 32 being ewe lambs and 22 ram lambs. The ram lambs were castrated at approximately 9 weeks of age and after this time are referred to as wether lambs.

Management.—The ewes and lambs were divided into three groups. Two of these groups were used in a parasitology experiment which is described by Spedding [1]. The first group consisted of eight sets of twins with their ewes which were reared indoors. It was intended that these lambs should be reared on their mothers and yet remain completely worm-free. To attain this end the pens were cleaned out every 2 days to prevent infection from the faeces of the ewes and only worm-free food was given in the form of frozen grass and lucerne, grass silage and hay. The second group was made up of thirty-eight lambs including both singles and twins and their ewes, and these were reared in the field. They were grazed on new leys, being moved to fresh ground every 2 days, using a system of hurdling in practice at the Station. This method of folding controls worm infestation and enables lambs to be reared practically worm-free, under grazing conditions. The third group contained the remainder of the ewes and lambs which were treated as a normal farm flock.

Technique of weighing and measuring.—The lambs were weighed in a canvas sling attached to a spring balance suspended from a portable wooden tripod. Birth weights were taken between 6 and 12 hours after birth; this gave sufficient time for the skin to dry while the lamb gained no appreciable weight from suckling. The lambs were numbered with paint on their sides in order of birth, and after their initial weighing they were allocated into two groups for convenience of weighing. Group A consisted of lambs born in the first half of the week and these were weighed on Mondays throughout the duration of the experiment. Group

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B consisted of lambs born in the second half of the week and these were weighed on Thursdays. Liveweights were corrected to weekly periods from birth by calculating the daily increase in any particular week and assuming the growth rate to be linear over the period of a week. No such calculations were made relative to the skeletal measurements.

The following measurements as used by Hamada [2] were taken using engineer's 12 in. calipers: (1) depth of chest, (2) length of hind cannon, (3) length of pelvis, (4) width of hooks, (5) width of hips, and (6) the circumference of the fore cannon, which was measured by using a piece of plastic-covered wire.

Depth of Chest. This is the vertical distance measured from the top of the spinous process of the third or fourth thoracic vertebra to a central point on the sternum in a vertical plane between the fore legs.

Length of hind cannon bone. This represents the distance between the condyles of the metatarsals and the posterior end of the heel bone (*tuber calcis*). Measurements were taken on the right hind leg.

Length of pelvis. The distance between the anterior edge of the hook bone (*tuber coxa*) and the posterior end of the pin bone (*tuber ischium*), measured on the right-hand side of the animal.

Width of hooks. The horizontal distance between the two *tuber coxae* of the pelvis.

Width of hips. This is measured between the two most lateral points of the major trochanters, while the legs are kept parallel and at right angles to the body.

Circumference of fore cannon. Measured at the most slender part of the metacarpal and as close to the skin as possible. Measurements were taken on the right fore leg.

The weights of the fifty-four lambs were recorded weekly for the first 5 weeks, and thereafter every 2 weeks until 20 weeks of age. It was not found possible, however, to continue measuring all the lambs and the number was accordingly reduced to thirty-six when lambing was completed. These thirty-six lambs consisted of all the single lambs together with a representative group of the twin lambs. All measurements were taken in duplicate during this second period of recording.

Nutrition.—The ewes and lambs kept indoors were fed on a low plane of nutrition, using grass and lucerne brought out from cold storage, along with grass silage and hay. The group folded over new leys was supported at a relatively high plane of nutrition, being moved on to fresh ground every two days. Those ewes and lambs kept as a farm flock were on a moderate plane of nutrition, since they were grazed on a new ley, but much more intensively than the group which was moved every two days. During March and April the ewes in all three groups received half a pound per head per day of crushed oats mixed with phenothiazine.

Results

Birth weights and measurements.—Table 1 shows that single ram lambs gave heavier birth weights than single ewe lambs, and twin ram lambs were heavier than twin ewe lambs. This is contrary to Hammond [3] who stated that 'At birth the male weighs only 94 per cent. of the weight of the female'. The difference is probably accounted for by the fact that the weights in Hammond's work were recorded on the second or third

day from birth, and he remarked 'It has been shown that the male loses more weight at this time than the female'.

There was a marked difference in skeletal size at birth between ram

TABLE 1. *Birth Weight of Lambs in Pounds*

Sex	*No. of lambs*	*Birth wt. in lb.*
Single rams	6	11·7
Single ewes	4	9·7
Twin rams	16	9·3
Twin ewes	28	8·6

lamb singles and ewe lamb singles, but a much smaller difference occurred between ram twins and ewe twins. This difference was probably due to competition in the foetal stage. According to Hammond [3] the ram has a greater potential growth rate than the ewe. Thus in the case of single lambs where there is no competition for the nutrients supplied by the

TABLE 2. *Measurements of Lambs from Birth to Twenty Weeks of Age*

Measurement	*Sex*	*No. of lambs*	*Birth mm.*	*5 wks. mm.*	*10 wks. mm.*	*15 wks. mm.*	*20 wks. mm.*	*Measurement at 20 wks. as % of measurement at birth*	*Average increase from birth to 20 wks.*
Depth of chest	Single wethers	6	155	213	247	270	287	185	
	,, ewes	4	141	200	237	253	267	189	86
	Twin wethers	10	140	193	227	248	265	189	
	,, ewes	16	141	192	222	242	257	182	
Length of hind cannon	Single wethers	6	149	181	200	208	213	143	
	,, ewes	4	140	170	189	196	203	145	44
	Twin wethers	10	144	173	190	201	209	145	
	,, ewes	16	141	168	184	193	199	141	
Length of pelvis	Single wethers	6[1]	114	167	198	217	228	200	
	,, ewes	4	112	156	191	202	213	190	93
	Twin wethers	10	108	150	177	196	208	193	
	,, ewes	16	108	149	176	194	204	189	
Width of hooks	Single wethers	6	74	123	153	167	173	234	
	,, ewes	4	68	120	151	157	171	251	139
	Twin wethers	10	67	107	132	148	158	236	
	,, ewes	16	67	108	133	146	158	236	
Width of hips	Single wethers	6	96	143	179	194	192	200	
	,, ewes	4	87	136	175	175	184	211	98
	Twin wethers	10	89	127	147	158	169	190	
	,, ewes	16	86	125	147	156	166	193	
Circumference of fore cannon	Single wethers	6	61	77	85	88	85	139	
	,, ewes	4	57	74	80	84	79	138	34
	Twin wethers	10	60	70	74	79	78	130	
	,, ewes	16	58	68	71	76	75	129	

[1] The pelvis length measurement at birth was taken only on 3 single ram and 2 single ewe lambs and on 5 twin ram and 9 twin ewe lambs.

ewe, a ram lamb will be larger in skeletal size at birth than a ewe lamb. With twin lambs the foetal competition may reduce the growth rate of the ram lamb more than that of the ewe lamb, so that the difference in skeletal size between twin ewe and twin ram lambs at birth will not be nearly so great. The mean measurements at birth are shown in Table 2.

Increase in weight.—To compare the growth of singles and twins and of wethers and ewes, the weights of the three groups of lambs were averaged. All the single lambs were reared out of doors on a high plane

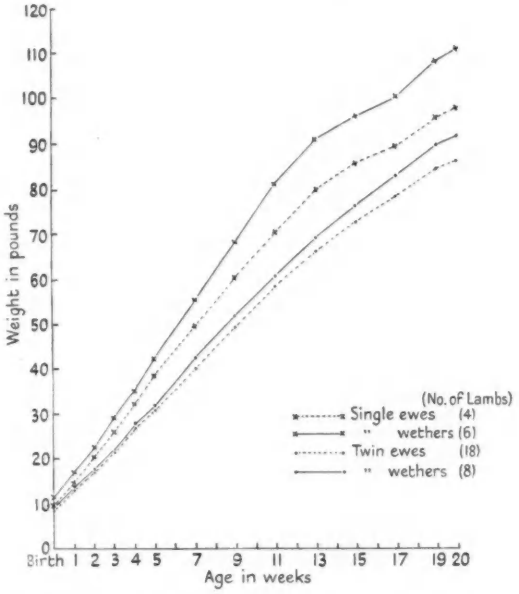

FIG. 1. Growth in weight of lambs reared out of doors.

of nutrition. Some of the twin lambs were reared indoors on a low plane of nutrition. Fig. 1 shows the increase in weight, from birth until 20 weeks of age, of the lambs reared out of doors.

All the lambs grew rapidly until the 7th week when a slight falling off was apparent in the growth curve of all groups. Single wether lambs showed a more rapid increase in weight than single ewe lambs. In the twins there was no apparent difference between wether and ewe lambs until the 13th week, when the former gained on the latter; the difference was not nearly as great, however, as the difference between the singles. The difference in liveweight at 20 weeks of age was approximately 6 lb. between twin wether lambs and twin ewe lambs. The difference between single wether lambs and single ewe lambs at this time was 13 lb.

A comparison was made between twins reared on a low plane of nutrition indoors and those reared on a high plane of nutrition at pasture. The

differences in liveweight increase as between high and low planes of nutrition are shown in Fig. 2. Little difference occurred until the lambs were 4 weeks old, when the milk supply of the ewes indoors began to fall off. From then on there was a rapid decline in the growth rate of the low-plane group. This resulted in a difference in weight of 20 lb. between the high and low groups at 20 weeks of age.

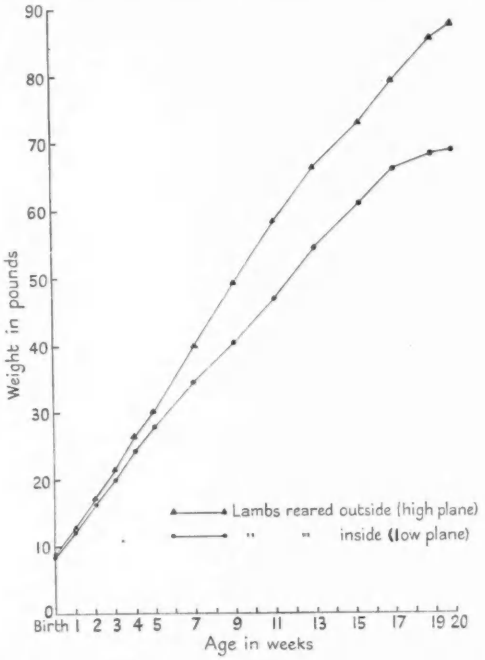

FIG. 2. Comparison of growth in weight between low and high plane nutrition groups (twins only)

Growth of the skeleton.—Table 2 shows the growth of the various parts of the skeleton from birth to 20 weeks of age. The greatest amount of growth occurred in the width of hooks. This, being a late maturing part, gave an average increase of 139 per cent. over the measurement at birth. The depth of chest, length of pelvis, and width of hips show increases of 86 per cent., 93 per cent., and 98 per cent. respectively. The length of hind cannon and circumference of fore cannon, which are early maturing parts, increased by 44 per cent. and 34 per cent. over birth measurements. These relative rates of growth of the different parts of the skeleton are in agreement with those recorded by Hamada [2]. Hamada suggested that selection for better conformation can be made from animals with the widest ratio occurring at birth and at marketing age, between trunk (particularly pelvis) measurements and length of

hind cannon. Commercially the pelvis region is considered the most valuable part of the animal.

It is not possible to compare directly the measurements of single lambs with those of twin lambs, because some of the twins were fed on a low plane of nutrition. Comparison of twin wether lambs and twin ewe lambs shows that there was a tendency for the ewe lambs to reach better conformation at an earlier age. This is indicated by the fact that the ewe lambs gave a shorter hind cannon measurement than wether lambs while the width of hooks was similar in both. Thus the ewe lambs showed a higher hooks : hind cannon ratio.

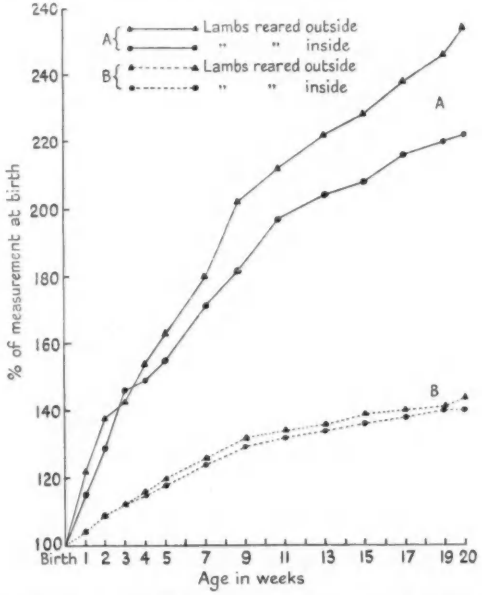

FIG. 3. Effect of plane of nutrition on: (*a*) A late maturing part of the skeleton (hooks); (*b*) An early maturing part of the skeleton (hind cannon)

The effect of a low plane of nutrition on skeletal development was compared with development at a higher plane of nutrition. The growth of the length of hind cannon and width of hooks is shown in Fig. 3. As the hind cannon is an early-maturing part of the skeleton, the plane of nutrition after birth had little effect on its growth and little difference was therefore obtained in the growth curves of the two groups. The width of hooks, which constitutes a late-maturing part, was markedly affected in its development by plane of nutrition. An average difference of 15 mm. in the width of hook bones was obtained between the high and low nutrition groups at 20 weeks of age.

The ratio $\frac{\text{Width of hooks}}{\text{Length of hind cannon}} \times 100$ clearly shows the effect of poor

nutrition on conformation at 20 weeks of age. Table 3 shows that the ratio for the low-plane group increased from 48 to 76 while that of the high-plane group increased from 45 to 81.

Accuracy of measurements.—As the lambs grew older certain measurements became more difficult to take owing to fleshing and wool growth. The measurements which showed least variation and which were easiest to take were the length of hind cannon, width of hooks, and length of pelvis. Measuring the circumference of fore cannon by plastic-covered

TABLE 3. *Measurements and Ratio of Width of Hooks and Length of Hind Cannon*

		Birth mm.	5 *weeks* mm.	10 *weeks* mm.	15 *weeks* mm.	20 *weeks* mm.
Low plane of nutrition	Width of hooks	68	106	129	142	151
	Length of hind cannon	142	168	184	193	198
	$\frac{\text{Hooks}}{\text{Hind cannon}} \times 100$	48	63	70	74	76
High plane of nutrition	Width of hooks	65	106	135	148	166
	Length of hind cannon	143	172	190	198	206
	$\frac{\text{Hooks}}{\text{Hind cannon}} \times 100$	45	62	71	75	81

wire gave rise to errors; it would have been more satisfactory to have taken a direct reading with a tape measure graduated in millimetres.

Summary and conclusions.—Weights and skeletal measurements were recorded of lambs from a pure-bred Clun flock, from birth to 20 weeks of age. Comparisons were made between singles and twins, wethers and ewes, and the effects of two systems of nutritional management.

The methods adopted for marking and weighing the lambs proved satisfactory. Certain measurements were both more accurate and more convenient than others. These included length of hind cannon, width of hooks, length of pelvis, and depth of chest. The length of hind cannon and width of hooks were most useful measurements as they represent respectively one of the earliest and one of the latest maturing parts of the skeleton. These two measurements are closely linked with conformation.

The results indicate that in the allocation of ewes and lambs to experimental groups, only ewes with twin lambs should be employed on account of the differences resulting from sex when single lambs are involved. If the numbers available are limited, necessitating the use of ewes with single lambs, then the groups to which these are allocated must be balanced for sex.

Acknowledgements.—The authors thanks are due to Dr. William Davies for facilities to carry out the work and to Mr. G. Pearson Hughes for his criticism and advice.

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(*Received* 16 *March* 1954)

THE TRANSIENT EFFECTS OF GRASSES ON THE STRUCTURE OF TROPICAL SOILS

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SHIFTING cultivation has been the traditional method by which the African farmer has maintained soil fertility. In Uganda this system approximates to a haphazard grass rest. Improvements in the physical conditions of arable top-soils which can be brought about by a rest period under elephant grass (*Pennisetum purpureum*) have been described by Martin [1]. Using a simple wet-sieving technique, he showed also that other East African grasses caused an increase in the percentage of water-stable aggregation of soils, but he obtained inconclusive results from measurements of total pore space. His investigations covered a range of the soils of Uganda, and his results from soil sieving supported the policy of following 3 years of arable cropping by 3 years of resting under grass. This policy had been the official recommendation since 1934, when it was adopted as a result of observations of African customs rather than on a basis of direct experiment [2].

This paper reports a study of the physical changes occurring in the soils of a field experiment laid down at Kawanda in 1949 [3] in which 3 years of contrasting crops and grasses were followed by uniform arable cropping.

Experimental

Field experiment details.—Kawanda is situated just north of Lake Victoria, and receives a bimodal rainfall averaging 43 in. per annum, although fluctuations about this value are large. The soil is an earthy red latosol derived from granite, and is typical of much of the cotton-growing area. Mechanical analysis of the first 3 inches gave mean values of 27 per cent. Coarse Sand, 17 per cent. Fine Sand, 46 per cent. Clay, 6 per cent. Silt, and 2·6 per cent. Organic Matter. Previous to the experiment the plots had undergone a 3-year period of intensive uniform cropping.

Twelve rotations were replicated five times in a simple randomized block design. For the first 3 years, 1949, 1950, and 1951, four treatments each of grasses, legumes, and root crops were grown, the same crop being grown continuously on any one plot. The grasses were not grazed, since the low cattle population of much of the cotton area leaves much of the resting land ungrazed. The term 'ley' is not, therefore, appropriate to such rest periods under grass. At the end of the 3-year period the plots were hand forked without burning of the grasses. They were then cropped uniformly, without fertilizers, maize being followed by cotton in 1952, and this by soya beans and cotton in 1953. Maize and cotton are being grown in 1954.

Water-stable aggregation was measured annually on all plots by

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Martin's technique of hand-operated wet sieving. Subsequent assessment of structure by volumetric techniques [4] were concentrated on nine of the treatments, grouped according to the degree of protection afforded to the soil during the first 3 years of the rotations. These were:

Three grasses

1. Elephant grass (*Pennisetum purpureum*).
2. Paspalum grass (*Paspalum notatum*).
3. Rhodes grass (*Chloris gayana*), resown annually.

Three cover crops

4. Kudzu (*Pueraria phaseoloides*).
5. Sweet potatoes (*Ipomea batatas*). (Grown as ground cover, and not harvested for 3 years.)
6. Leucaena (*Leucaena glauca*).

Three cultivated crops

7. Groundnuts (*Arachis hypogaea*). Replanted eight times in 3 years.
8. Sunnhemp (*Crotalaria juncea*). Resown six times in 3 years.
9. Cassava (*Manihot utilissima*). Soil kept clean by inter-row cultivation.

Wet-sieving tests.—Table 1 summarizes the results of wet-sieving tests made annually. Comparisons between sampling dates are not fully reliable, since Martin's wet-sieving method involves a subjective estimate by the operator of the number of immersions required to produce clean crumbs. The higher values in the final column may have been due to a change of operator. A uniformity trial, conducted by Manning on a large volume of carefully mixed soil, showed statistically significant differences between operators and between days [3]. Table 1 shows significantly less water-stable aggregates under the cultivated crops than under the grasses in each year. These differences increased each year, the cover crops giving intermediate results, which were significantly different from the other groups in the second and third year. Although cultivated and resown twice yearly, the sunnhemp gave aggregation results similar to those of the cover crops rather than the cultivated crops. All of the results showed a marked downward trend in the level of aggregation. This trend is heaviest with cultivated crops and least with grasses. Only elephant grass produced an increase in aggregation, and this rather slight increase from 3 years of grass rest had disappeared after one year of arable cropping.

These results differed unexpectedly from those reported by Martin [1], and the soil structure was therefore examined, in December 1952, by a number of different methods.

Comparison of Techniques of Wet Sieving

Two cropping treatments, cassava and elephant grass, which from previous reports would be expected to have achieved a substantial difference of structure in 3 years, were selected for a detailed comparison of

TABLE 1. *Proportion of Soil in Water-Stable Aggregates Retained by the ½-mm. Sieve*

	Initial conditions April 1949	*Cropping treatments 1949–51*	*After 1 yr. treatment July 1950*	*After 2 yrs. treatment May 1951*	*After 3 yrs. treatment Jan. 1952*	*End of resting period*	*In seed-bed for maize Feb. 1952*	*After cotton crop Feb. 1953*
3 grasses . . .	51·6	Elephant grass	54·2	56·8	53·7	Maize and then cotton grown on all plots during 1952	46·8	51·0
	52·9	Paspalum grass	44·9	51·6	45·6		48·8	47·7
	48·6	Rhodes grass	51·6	47·5	44·1		44·7	49·2
Means for grasses .	*51·0*		*50·2*	*52·0*	*47·8*		*46·8*	*49·3*
3 cover crops . .	53·6	Kudzu	47·4	47·0	44·5		38·8	45·0
	49·8	Sweet potatoes	44·3	40·1	35·6		36·8	43·6
	48·6	Leucaena	51·1	46·0	39·8		40·3	46·8
Means for cover crops	*50·7*		*47·6*	*44·4*	*40·0*		*38·6*	*45·1*
3 cultivated crops .	49·0	Groundnuts	44·4	37·2	27·8		27·1	40·6
	52·2	Sunnhemp	50·2	39·6	39·1		35·5	43·2
	48·5	Cassava	43·8	35·5	27·5		29·4	41·3
Means for cultivated crops . . .	*50·0*		*46·1*	*37·4*	*31·5*		*30·7*	*41·7*
Least Sig. Diffs. at P = 0·05 for:								
Treatments .	6·1		7·0	6·7	7·7		6·6	6·8
Means . .	*3·5*		*4·1*	*3·9*	*4·4*		*3·8*	*3·9*

the modified sieving techniques described by Martin[5] and by Pereira[4]. The differences in method lay, first in the manner of subdividing the samples for sieving, and secondly in the manipulation of the sieves in water. Prior to 1945 Martin crumbled the soil by hand to pass a 3-mm. sieve. After 1945 the larger crumbs not passing the 3-mm. sieve were 'mixed back' into the finer soil. Pereira dry-sieved the weighed air-dry soil over a bank of sieves from $\frac{1}{2}$ mm. to 5 mm., weighed and discarded the soil passing $\frac{1}{2}$ mm., and quartered each crumb-size separately. The quartered crumbs were pooled to give subsamples which thus contained the crumb sizes in the proportions present in the original bulk sample. Wet sieving by Martin's technique was by hand, the sieves being gently

TABLE 2. *Effects of 3 Years' Rest Under Elephant Grass*

Cropping system	*Penetrometer blows per core*	*Per cent. of soil in crumb* $> \frac{1}{2}$ *mm.*		
		Dry sieving	*Hand sieving*	*Mechanical sieving*
Continuous arable (3 yrs. cassava; 1 yr. maize and cotton) . .	13·5	21·5	45·8	43·2
Grass rest and arable (3 yrs. grass; 1 yr. maize and cotton) . .	13·7	22·6	48·4	47·0
Least Sig. Diff. P = 0·05 . .	2·6	3·5	6·9	7·6
Coefficient of variation per cent. .	9·4	15·6	14·5	16·9

immersed and lifted out of the water until the crumbs appeared clean. Pereira used a mechanical oscillator on which the sieves remain under water and are raised and lowered sixty times, rotating approximately 20° on each stroke. In this test strictly comparable subsamples were obtained by the dry-sieving technique, and were then wet-sieved by the two methods described, employing an operator with considerable practice in the hand-sieving.

When sampled, the plots were under cotton, at the end of the first year of uniform arable cropping. They were equally dry, and the samples were taken with the 4-in. diameter core-sampler described by Pereira [4], penetrometer counts being taken for the number of blows of the sliding hammer required to reach the 3-in. depth. This was done in an attempt to compare the resistance of the soils to tillage instruments. Penetrometer counts, and the results of the sieving of twelve subsamples from each treatment, are given in Table 2. Crumb results are expressed as percentage of oven-dry, gravel-free soil.

None of the tests showed any significant differences between the soil conditions after the first year of intensive cropping, the two methods of wet-sieving giving concordant results.

A complete set of samples from all treatments was obtained two months later in February 1953. Duplicate composite samples were taken from each plot, one being quartered and hand-sieved in water by Martin's method, and the other subdivided and mechanically wet-sieved by Pereira's technique. The results are summarized in Table 3.

The aggregation percentages are lower than in Table 2, since the February samples were taken to the full depth of the dark top-soil (6 in. to 9 in.) by taking cores to 9 in. and cutting off the visible red subsoil. (This had been the standard method of sampling in this experiment.) Although placing the groups of treatments in the same order, the two methods of sieving showed some serious discrepancies and the correlation coefficient was only 0·67. The hand-sieving method appeared to include some bias in favour of the grasses, e.g. it gave the difference between the elephant grass and cassava treatments as significant at the

TABLE 3. *Comparison of Sieving Methods*

Treatment	*Water-stable crumb > ½ mm. as per cent. oven-dry gravel-free soil*			
	Hand-sieving		*Mechanical sieving*	
1 yr. maize and cotton after 3 yrs. of:				
Elephant grass	51·0		46·5	
Paspalum grass	47·7		47·3	
Rhodes grass	49·2		41·3	
Mean		49·3		45·0
Kudzu	45·0		46·6	
Sweet potatoes	43·6		40·7	
Leucaena	46·8		44·2	
Mean		45·1		43·8
Groundnuts	40·6		39·1	
Sunnhemp	43·2		41·5	
Cassava	41·3		41·8	
Mean		41·7		40·8
General Mean	45·4		43·2	
Standard Error per sample	5·3		3·9	
Coefficient of Variation	12·0		9·2	
Least Sig. Diff. P = 0·05	6·8	3·9	5·0	2·9
P = 0·01	9·1	5·2	6·6	3·8
Correlation Coefficient (Significant at P = 0.001)		0·67		

1 per cent. level, while the mechanical method agreed with the data in Table 2 in showing no significant difference between these treatments. Also the Rhodes grass aggregation is shown as significantly higher than that of Kudzu by hand-sieving, but significantly lower by mechanical sieving. The differences between the two treatments were examined for relationship to the dry-sieving results, but no significant correlations were found. A possible reason for this apparent bias may be that soil crumbs mechanically bound by the fibrous roots of grasses appear 'clean' to the operator at an earlier stage in the hand-sieving than do the crumbs bound by amorphous organic matter. The mechanical oscillation treats all samples alike, and gives them a more severe water treatment. The method of subdividing the dry sample may also influence the results.

These differences emphasize the highly arbitrary nature of wet-sieving tests as criteria of soil structure.

Volumetric sampling of the first three inches of soil.—Using the hammer-driven core-sampler, sleeved cores of 4 in. diameter and 3 in. depth were taken in duplicate from three plots of each of the nine treatments described above, giving fifty-four cores in all. Penetrometer measurements were again taken as a test for differences in ease of working of the soil as a

TABLE 4. *Penetration Tests for Compactness of Soil*

Treatment	*Field moisture content (% oven dry wt.)*	*Blows for 3 in. penetration of core sampler*
One year of uniform arable after 3 yrs. treatment as below:		
Elephant grass	9·5	12·5
Paspalum grass	10·3	15·7
Rhodes grass	8·9	11·5
Kudzu	8·8	11·3
Sweet potatoes	7·4	11·7
Leucaena	8·5	13·2
Groundnuts	8·2	11·8
Sunnhemp	8·0	13·7
Cassava	9·1	12·8
Least Sig. Diff. at P = 0·05	1·8	5·9

result of the resting treatments. Consistent differences in the appearance of the soil surface were observed between treatments while sampling. After the cassava and groundnut crops the soil had been beaten flat and smooth by rainfall; the grasses had left more cloddy surfaces, the paspalum leaving the roughest and the Rhodes grass the smoothest soil surface. The remaining crops had left soils in intermediate conditions, with little sign of desirable structure.

Table 4 shows that the penetrometer measurements were too variable to give any significant differences, but suggests that the paspalum left the soil harder rather than easier to work, in spite of a slightly higher moisture content. This was confirmed by observations while digging out the core-sampler. Thus any improvements in ease of working of the soil as a result of the resting period under grass had been lost after one year of intensive arable cropping.

Soil porosity.—The cores were wetted under a partial vacuum and brought to equilibrium on tension plates drained at 20-cm. and 330-cm. water levels. After static-head percolation measurements they were subjected to artificial rainfall tests and finally broken up, the real volume of soil being measured by displacement in water. The results for individual treatments are summarized by Fig. 1, and the comparison of groups of treatments is shown in Table 5.

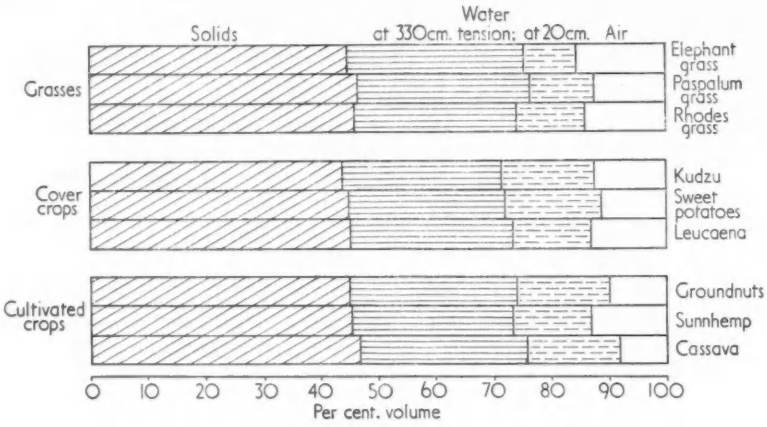

FIG. 1. Volumetric effects of crops on soil structure

TABLE 5. *Effects of Treatments on Soil Porosity*

Treatment	*Pore space per cent. of total soil volume*					
	Freely drained pores: 20 cm. water tension		*Pores drained at field capacity 330 cm. water tension*		*Total pore-space*	
1 yr. of uniform arable after 3 yrs. treatment as below:						
Elephant grass	16·3		25·1		55·0	
Paspalum grass	12·5		23·9		53·4	
Rhodes grass	14·1		26·2		54·2	
Mean		14·3		25·1		54·2
Kudzu	12·2		26·4		54·9	
Sweet potatoes	10·4		27·1		54·6	
Leucaena	13·2		28·6		55·8	
Mean		11·9		27·4		55·1
Groundnuts	9·9		25·4		54·5	
Sunnhemp	13·6		26·6		54·2	
Cassava	8·7		24·7		54·2	
Mean		10·7		25·6		54·3
Least Sig. Diff. at P = 0·05	3·3		3·2		1·8	
L.S.D., means		1·9		1·8		1·0

The freely drained pore-space, emptied at the slight tension of 20 cm. of water, was significantly greater after the grass treatments than after either the cover crops or the cultivated crops. Among individual treatments, elephant grass had left a higher pore-space than paspalum, while the sunnhemp had left a pore-space significantly better than that from the other two cultivated treatments, groundnuts and cassava. As shown later in this paper, these increases resulted in small but significant improvements in the ability of the surface soil to accept and to transmit rainfall.

TABLE 6. *Infiltration and Percolation Tests*

Treatment	*Infiltration rates in inches per hour under rainfall at 6 in./hr.*		*Percolation rates in inches per hour under constant head*	
1 yr. of uniform arable after 3 yrs. of treatment as below:				
Elephant grass	4·12		16·5	
Paspalum grass	4·53		13·2	
Rhodes grass	4·13		14·3	
Mean		4·26		14·7
Kudzu	3·74		12·1	
Sweet potatoes	4·09		12·2	
Leucaena	3·83		10·0	
Mean		3·89		11·4
Groundnuts	3·41		8·8	
Sunnhemp	3·43		9·6	
Cassava	3·74		10·2	
Mean		3·53		9·5
Least Sig. Diff. at P = 0·05	1·03		4·3	
" " " " " , means		0·60		2·5

Differences in soil aeration were estimated from the relative volumes of air space at field capacity. A check was made on the tension level which best represents field capacity in this soil, by observations on six additional cores from a nearby fallow area, part of which had been heavily mulched with grass. This grass mulch afforded protection adequate to prevent most, but not all, of the evaporation from the soil surface in the prevailing hot dry weather. The field moisture content of the first 3 in. under these conditions was 30·5 per cent. When brought to equilibrium at a tension of one-third of an atmosphere the moisture content of these cores was 33·4 per cent. Table 5 shows that at this tension about one-half of the total pore-space is air-filled. The cover crops had the most effect on this aspect of soil structure, by leaving an air-space at field capacity significantly greater than that after either grasses or cultivated crops. The coarse and vigorous root-system of *Leucaena glauca* had left a volume of air-space significantly greater than that left by elephant grass. Leucaena also gave the highest value for total pore-space, but this is a

relatively insensitive measure of soil structure, showing no significant differences between the main groups of treatments.

Infiltration and percolation of rainfall.—Using the techniques described by Pereira [7], the cores were tested for steady percolation rates under a constant head of 1 cm. of water and were then submitted to an artificial rain-storm of 1 in. of water in 10 minutes, delivered in drops of 6 mm. diameter. Table 6 shows that the soils after resting under grass had retained a small advantage in the rates of infiltration of rainfall, and a substantial advantage in rates of percolation. It is noteworthy, on comparing Tables 5 and 6, that these advantages reflect the persistence of the large pores drained at 20 cm. tension rather than the pore-space drained at one-third of an atmosphere. On inspection of the samples, many more insect holes were visible in the cores from the grass-rest than from the continuous-arable treatments.

Rate of Deterioration of Soil Structure

In the estimation of soil structure by wet-sieving methods the results have been shown in this series of experiments to be affected to some extent by the nature of the arbitrary techniques employed. In spite of this disadvantage, the general trend of soil conditions, as far as they may be distinguished by water-stable crumb percentages, has been one of transient improvement after the grass-rest treatments, the soil returning approximately to its original condition during the first year of arable after the breaking of the grass. The soils receiving continuous cultivation treatments appeared to suffer a continuous decline in physical condition.

More detailed study of the physical differences persisting in these soils after the first year of uniform arable cultivation showed that the grass rests had conferred no continuing advantage in ease of working, in total pore-space, or in the volume of soil air space drained at field capacity.

Table 7 summarizes the residual effects of grass rests as compared with continuous cultivation and shows the degree to which different physical properties of the soil have been affected. The advantage in the volume of freely drained pore-space, amounting to $3\frac{1}{2}$ per cent. of the soil volume, is attributed to the greater insect activity associated with the residues of the grass roots, numerous insect holes being visible in the soil cores. By their continuity these holes, although small in volume, caused a substantial increase in the rates of percolation of water through cores which had been gently wetted under vacuum. The grasses had not left a sufficient improvement in soil stability to enable these channels to give a similar large increase on the rates of rainfall acceptance, which were low for all treatments. After breaking from well-established grass, soil conditions are normally adequate for the acceptance of very heavy rain. This is well illustrated by the results of another study described below. The rainfall acceptance rates in Tables 7 and 8 were determined on the same equipment by a carefully standardized technique. Thus the acceptance of only $4\frac{1}{2}$ in. out of the 6 in. per hour applied, as compared

with acceptance of 3½ in. per hour on the continuously cultivated treatments, suggests that much of the advantages derived from the 3 years of resting under grass had already been lost after a year of arable cropping.

TABLE 7. *Residual Effects of Resting Land under Grass*

Methods of assessment of structure	*Mean results for groups of three treatments*		
	1 year after breaking the 3-year grass rest	*Under continuous cultivation*	*Percentage improvement*
I. *Tests on soil cores (4 in. diameter and 3 in. depth):*			
Total pore-space (% by volume)	54·2	54·3	Nil
Pore-space drained at 20 cm. water tension (% volume)	14·3	10·7	34
Rainfall acceptance (from 6 in. per hour applied)	4·26	3·53	19
Percolation rate, in. per hour, under constant head	14·7	9·5	55
II. *Tests by soil sieving (Water-stable aggregates* $>\frac{1}{2}$ *mm.):*			
By quartering dry sample and hand-sieving in water	49·3	41·7	18
By dry sieving, quartering fractions, and mechanical sieving in water	45·0	40·8	10

Data from a Contrasting Soil Type

Well-replicated rotation trials of long duration are evidently needed to resolve such problems, but these elaborate field trials are scarce enough in well-developed countries, and rare in East Africa. Some useful indications of major differences in soil conditions may, however, be obtained by sampling adjacent areas of a uniform soil type under contrasting crop rotations. Pereira [6] briefly reported such a study in Kenya on seven adjacent 3-acre areas at different stages in a simple sequence of: Old plantation coffee → Elephant grass for a varying number of years → New plantation coffee. The areas lay across a uniform slope, and were of identical agricultural history. The grass grew 5 to 6 ft. tall and was cut and removed twice a year; some light grazing occurred after cutting. The soil was Kikuyu Red Loam, a red latosol derived from sheet lava (trachyte) and having, in the top-soil, approximately 63 per cent. clay, 24 per cent. silt, and 13 per cent. sand. A part of the data is relevant here, and is given in Table 8 in more detail than in the original report, which was of a non-technical nature.

With the reservations required in the absence of statistical elimination of soil differences between areas, these measurements indicate:

1. that a very great structural improvement continued for at least 5 years under elephant grass, resulting in a very high (99 per cent.) efficiency in the reception of heavy rainfall;

2. that most of the improvements made during 4 years of grass rest were lost in 2 years of subsequent clean cultivation of young coffee; and

TABLE 8. *Effects of Crop Rotation on Soil Structure*

Methods of assessment of soil structure	*After continuous coffee cultivation for 30 yrs.*	*Coffee removed and elephant grass grown for:*			*After 4 yrs. grass and 2 yrs. subsequent cultivation*	*After 2 yrs. grass and 4 yrs. subsequent cultivation*
		4 yrs.	*5 yrs.*	*6 yrs.**		
Per cent. of soil in crumbs greater than ½ mm. diameter:						
Dry soil crumbs	69	72	72	74	62	58
Water-stable crumbs	43	59	62	60	48	43
Pore-space per cent. of total soil volume:						
Total pore space	64·9	64·0	67·5	64·7	64·0	63·6
Large pores drained at tension of 50 cm. water	24·2	23·6	26·8	24·6	21·9	19·4
Rainfall acceptance and transmission (in. per hour):						
Infiltration under rainfall at 6 in. per hour	4·20	5·52	5·94	4·98	4·98	3·96
Percolation under constant head	9·07	13·12	22·33	19·66	5·72	4·85

* After deep hand-cultivation of a severe infestation of *Digitaria abyssinica*.

3. that where only 2 years of elephant grass were followed by 4 years of soil exposure by clean cultivation, the resulting physical conditions were less favourable than those under long-term continuous cultivation. The latter indication was supported by field observation of soil appearance after rain.

Soil moisture measurements in these areas illustrated an important point in the planning of tropical rotations where rainfall is a limiting factor. When the elephant grass was dug out at the end of the dry season, the soil was at or near to wilting-point to a depth of 10 ft., and contained 36 in. of water in this depth. A nearby bare fallow contained 45 in. of water in 10 ft., thus providing 9 in. of available water. Such a severe water deficit following a grass rest may seriously affect the next crop if the rainfall distribution in the early part of the growing season should be unfavourable.

Conclusions

The results reported here illustrate the need to employ more than one type of measurement as a criterion for estimating soil structure. They also demonstrate the value of the new technique of applying measured rainfall to the surface of undisturbed soil cores. The measurements confirmed by a number of tests the important soil improvements achieved during a rest period under grass, but showed that these are rapidly lost during the arable cultivations which follow. The duration of the benefits of soil improvement under grass requires further critical examination, particularly because the adoption of alternate husbandry rotations is being strongly urged throughout East Africa. The rate of deterioration of soil structure during the arable break is as important as its rate of restoration under grass in the planning of crop rotations for the tropics. Although Maher [8] has drawn attention to this aspect of the problem, very few results have yet been published.

The above results from the rotation experiment showed that the physical benefits of the grass treatments were substantially better than those from the cover crops. Both kudzu and sweet potatoes gave full soil protection and vigorous vegetative growth for 3 years, but failed to leave any important improvements in physical properties. The tall bushy perennial legume *Leucaena glauca* gave far less soil cover, but its vigorous root system left an improvement in soil aeration which remained significantly large after a year of arable cultivation. This soil, although in a more porous condition, failed to resist the impact of heavy rainfall on its surface, so that there was no improvement in the infiltration rate which is critical for the prevention of erosion. The growing of six successive seed crops of the legume sunnhemp, although leaving a volume of larger pore-spaces greater than that of other continuous arable treatments, gave no improvement in either infiltration or percolation rates. Only with the grasses were the improvements in pore-space stable enough to improve the acceptance and transmission of rainfall.

The physical condition of the soil, although of great importance under tropical conditions, is only part of the effect of crop rotations. The

collection of nutrients by deep-rooting grasses and legumes, and their concentration in available forms in the surface soil, may well have direct effects on the yields of following crops. The relationships between crop yields, nutrient concentrations, and soil structure for the Kawanda experiment are being examined by Mills and Chenery.

Summary

A detailed study was made of the differences in soil structure in a crop-rotation experiment on a tropical soil. Two different techniques of soil sieving were compared with volumetric measurements of pore-space, and with percolation and rainfall-acceptance tests on soil cores. Three grass species, three cover crops, and three cultivated crops were each grown continuously for 3 years. All treatments were then given one year of intensive uniform cropping before the structure comparisons were made.

The two tests for water-stable aggregation showed serious discrepancies, but they both agreed with the remaining tests in showing general differences between the groups of treatments after grass rest and those after continuous cultivation. Rainfall infiltration rates were comparatively low after only one year of arable cropping, indicating a rapid loss of the benefits built up under a grass rest. A similar set of tests, on adjacent areas of a rotation on a lateritized volcanic clay, showed even more rapid loss of physical structure after the breaking of grass.

These results illustrate the need to measure rates of run-down as well as build-up of soil structure, and the desirability of using physical tests more realistic than wet sieving.

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(*Received 30 April 1954*)

ENVIRONMENTAL AND GENETICAL EFFECTS ON MILK YIELD IN PAKISTANI BUFFALO

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IN Pakistan the average agricultural holding is less than 12½ acres. There is a shortage of water and no artificial fertilizers. The average farmer is poverty-stricken and cannot afford to keep many animals; those he does keep must be utility animals which can exist on poor fodder. They must be able to do all the ploughing and carting, supply him with milk and ghee (clarified butter), produce manure for the land, and finally be killed for meat and hide.

The buffalo admirably fits these requirements. In 1945 there were 5·6 million within the present boundaries of Pakistan, compared with 24 million cattle.

There are three breeds of buffalo in west Pakistan—the Nili and Ravi in west Punjab and the Khundi in Sind. This study is concerned with the first two breeds, which differ only in details of conformation. The first is found in the districts of Montgomery and Ferozepur (east Punjab) near the river Sutlej; the second is found along the river Ravi in Lyallpur and Montgomery districts. Mature males weigh about 1,300 lb. and females about 1,000 lb. The average milk yield in 250 days is 3,500 lb. (Nili) and 4,000 lb. (Ravi).

The habitat of the Nili and Ravi in the Punjab lies between 29·5° and 32·5° N. latitude and 71° and 75° E. longitude. The area is dry and subject to extremes of temperature. The summer rains (monsoon) start about the middle of June and last until about the middle of September. In winter the north-east depression causes rain from December to mid-March. Summer rainfall is 3–10 in. and winter 1–5 in., but the average annual rainfall does not exceed 5–10 in. In winter the day temperature seldom rises above 75° F., and in December and January the temperature often falls below freezing point at night. From February onwards the temperature rises at the rate of about 10° F. per month until it reaches 110°–123° F. The shade temperature in summer at about 3 p.m. is 103° F. and the night temperature averages 81° F.

The buffalo breeding areas lie along the rivers. Steer progeny are in great demand for ploughing in the rice-growing tracts of the province where the soil is heavy clay. From the agricultural point of view there are two cropping seasons in the Punjab—summer and winter. The grazing areas or pastures, as a result of the extremes of climate, do not provide enough grass for the cattle all the year round. The main fodder crops are

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[Empire Journ. of Exper. Agric., Vol. 22, No. 87, 1954.]

jowar (grain sorghum), maize, berseem (Egyptian clover), cowpeas, turnips, and Japan rape.

The Government Buffalo Breeding Farm, Bahadurnagar.—The records used in this study are from the Buffalo Breeding Farm at Bahadurnagar, which is near Okara, Montgomery, in the centre of the breeding area of the Nili and Ravi buffaloes. It is the only government buffalo breeding farm in Pakistan, apart from the military dairy farm at Okara which is maintained for the production of condensed milk for the troops.

In 1936 Bahadurnagar Farm of 3,050 acres was leased by the Punjab Government to R. S. Chaudri Mahla Singh; he was required to maintain 300 adult buffaloes and young stock on the farm, which was periodically inspected by officers of the Veterinary Department. After the partition in 1947 the lessee migrated to India and since then the farm has been under the direct control of the Animal Husbandry Department of the Government of Punjab (Pakistan). It yields a net income of 100,000 rupees (about £11,000) to the Government exchequer.

The stock comprises about 400 adult buffaloes and a similar number of followers. It is a mixture of the Nili and Ravi breeds; there are also some 'Dheli' (loose-horn) type, but these are being gradually eliminated. No animal has been bought in since 1947. Some of the bulls now working on the farm are home-bred.

For ease of management the herd is divided into three groups. The first group includes Ravi-type animals whose milk yield in their third lactation is 500 gallons or more, and the second group those below 500 gallons. The third group includes the smaller animals with convex head conforming more to the Nili type; their yield is 450 gallons or more. Lower yielders are culled. This division on type is made at one year of age. Nili dams usually have daughters whose conformation places them in the Nili group. Each group grazes on a separate pasture and has the same number of herdsmen. Since groups 1 and 2 each have only about 50 animals in milk, compared with 100 in group 3, they naturally get better treatment. The groups are not permanently separated; animals born in one group may be transferred to another on the basis of their performance during their first three lactations. Bulls are divided into two groups only—Nili and Ravi.

There have been great fluctuations in the level of management of the herd. During the period 1947–52 covered by the records here analysed there have been no less than five different officers-in-charge. The level of management is bound to vary according to the ability of the officer-in-charge, his efficiency in the supervision of the staff, his system of crop husbandry, and methods of culling. Furthermore, the period 1947–9 was a time of great financial stringency owing to the results of partition. The animals were fed chiefly on green fodder and roughage, as no money was available to buy concentrates. In 1950, when the author (M. A.) took charge of the farm, the Director of the Animal Husbandry Department agreed to provide funds for improved feeding and since then the herd has been fed on scientific lines.

Experience has shown that adult buffaloes need 80–120 lb. of green fodder per day and about 6 lb. of dry fodder such as chaffed wheat straw

(*bhoosa*). They require 2 lb. of concentrates for maintenance and an additional 3 lb. per gallon of milk. Ashfaq [1] has worked out suitable rations which supply the necessary quantities of T.D.N. and digestible protein. The green fodder consists of green maize and green cowpeas or green jowar and mixed grass in summer and green berseem, fodder turnips (with tops) or green sarson (colza seed) in winter. The concentrate mixture is made of crushed grain, cotton-seed cake, wheat bran, and toria (rape seed) cake or crushed yellow maize. Ashfaq and Shah [2] have further discussed these rations, which have been fed at Bahadurnagar Farm since 1950 except when such commodities as wheat bran and cotton-seed cake were not available on the market. The rest of the concentrates were farm produced.

The cows are milked twice daily. Owing to shortage of labour and equipment the calves are not weaned, so the milk obtained at milking is only that surplus to the calf's requirements. Once a week, however, the animals are completely milked out during 24 hours and the calves are artificially fed. This one day's record is used to compute the week's total yield. Owing to the absence of Gerber apparatus no fat testing is possible. (In fact the butterfat percentage of buffalo milk is about 7.) No facilities for weighing animals are available.

Weaning and artificial feeding of calves would involve the sterilization of all utensils and the preparation of artificial food. Facilities for this are not available and in their absence artificial feeding would lead to high calf mortality. Therefore the calves suckle their dams for the greater part of the lactation. The calves are divided into three batches aged 0–3 months, 3–6 months, and 6–9 months. They are given green fodder in addition to milk.

Up till now breeding has been more or less at random. The aim of the Department is to produce animals of uniform appearance and the type favoured by the breeders. It wishes to produce economical animals by decreasing body size and at the same time increasing milk yield. Since 1950 the culling of animals giving less than 300 gallons in their first lactation and not pregnant within 6 months has started with some rigour.

Milking cows are transferred from the farm to the Government Dairy Farm, Montgomery, which is run by the Animal Husbandry Department to supply milk to Montgomery town. Their calves are received back after weaning to be reared at Bahadurnagar. Bulls are issued to local bodies and private breeding institutes for the upgrading of their stock. They have also been in demand abroad and have been exported to Australia, Indo-China, Malaya, and Indonesia.

Material—The material studied consisted of 754 lactation records from 338 buffalo cows which calved at Bahadurnagar Farm during the years 1947–51. There were one, two, three, or occasionally four records per cow. For each calving was recorded the date, the number of days in milk, the number of days dry and either the milk yield in 300 days (187 animals) or for the whole lactation (151). For most of the animals (excluding forty-four purchased) information was also available on date of birth, names of parents, and date of first calving. What was not stated was the serial number of the lactation in cases where the first recorded lactation

was not the first lactation in the animal's life. The ages of the buffaloes at the first recorded lactation varied from 3 to 13 years.

Records with lactation lengths of less than 100 days were discarded.

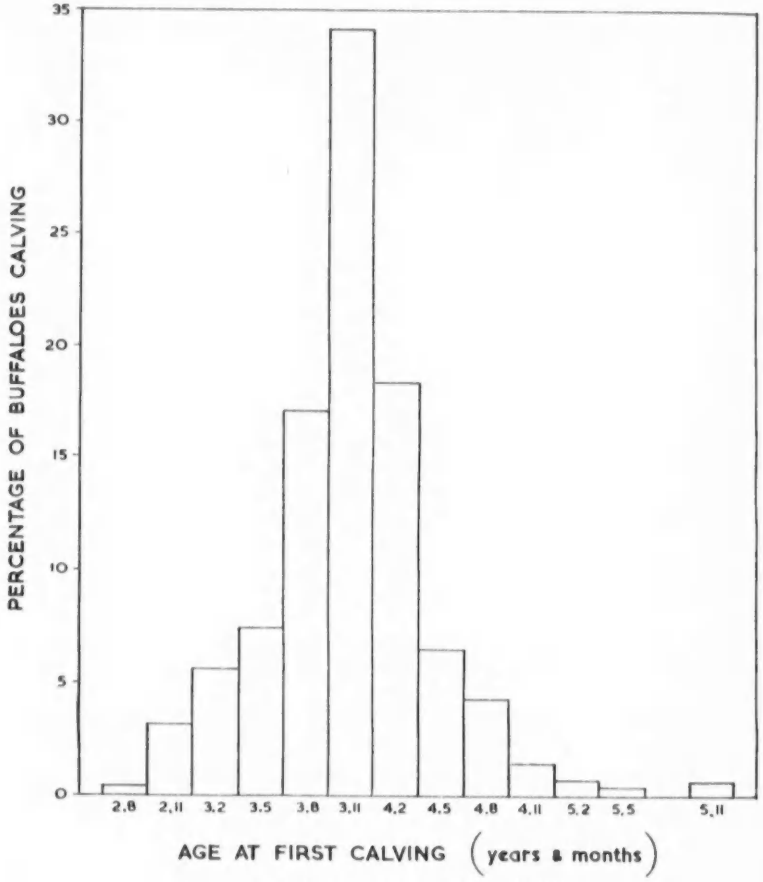

FIG. 1. Distribution of Age at First Calving

There were in all nineteen of these. Some animals were specified as sold or ill and it was assumed that similar accidents, or the death of their calves, had cut short the lactation of the others.

After a preliminary account of the reproduction of the buffalo this study is devoted to an investigation of the effect on milk yield of length of lactation, year of record, month of calving, and dry period. After suitable corrections for these environmental factors, the repeatability of milk yield and its heritability are calculated.

Breeding Biology

Age at first calving.—Heifers are run with the bull as soon as they reach 800 lb. body weight or 2½ years of age, whichever is earlier. Date of birth and date of first calving were recorded for 279 animals born in 1936 or later and calving in 1939 or later. The age at first calving varied from 2 years 9 months to 6 years. The mean was 3 years 11 months. The calvings were grouped into frequency classes of 3 months and the distribution is shown in Fig. 1.

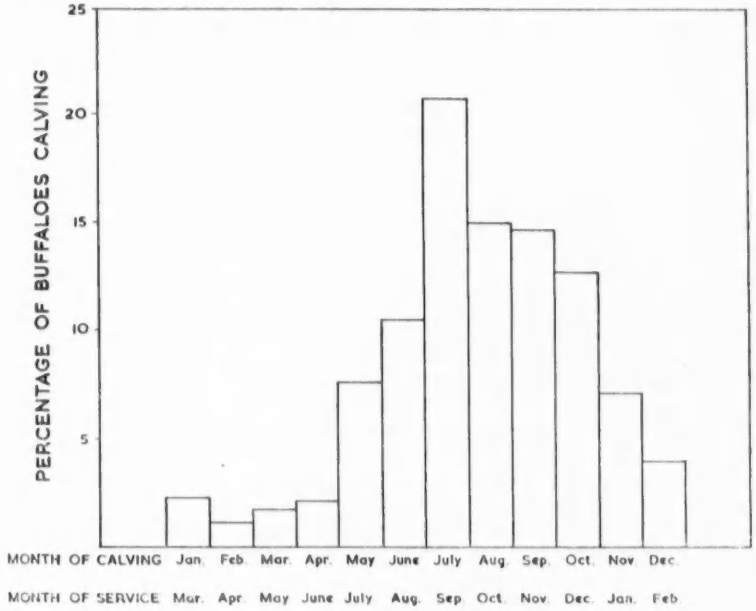
PERCENTAGE OF BUFFALOES CALVING
25
20
15
10
5
MONTH OF CALVING Jan. Feb. Mar. Apr. May June July Aug. Sep. Oct. Nov. Dec.
MONTH OF SERVICE Mar. Apr. May June July Aug. Sep. Oct. Nov. Dec. Jan. Feb.

FIG. 2. Monthly Distribution of Calving

Month of calving.—For 759 births the month of calving was tabulated and the histogram of Fig. 2 plotted. The same monthly distribution was obtained when first calvings only were considered. It will be seen that calvings are most frequent in summer and autumn with a maximum in July in the middle of the hot, wet season. Spring calvings (January to April) are very infrequent.

Since the bulls are allowed access to the cows throughout the year the frequency of calvings shows the frequency of fertile matings 10 months earlier (305–15 days being the gestation period of the buffalo). It is clear that there is an increase in the rate of fertile services in July with the advent of the rainy season; it reaches a peak in September and then falls off during winter. This seasonal effect may reflect the seasonality of oestrus or of the sexual activity of the males; indeed in May and June

when fertile services are at their minimum the temperature is highest and animals often fail to come on heat.

Calving interval.—Since our primary interest in calving interval was its repeatability, only those cows with at least three consecutive calvings were included in this analysis. There were 213 such animals; the average of 550 calving intervals was 467 days. When the calving intervals are arranged according to the year of the first calving of the pair (Table 1)

TABLE 1. *Calving Interval by Years*

Year of calving	*Number of animals*	*Average interval following calving (days)*
1947	19	614
1948	123	528
1949	148	484
1950	146	436
1951	114	385
Total	550	Mean 467

it is seen that this average does not by any means represent the present state of affairs.

The improvement in management already referred to is reflected in the decrease in calving interval which has been reduced in 4 years from 20 months to less than 13.

Age also has an effect on calving interval as shown in Table 2. It is clear that the first two calving intervals are longer than average, but after 6 years old age has no effect.

TABLE 2. *Effect of Age on Calving Interval*

Age at calving (years)	*Number of animals*	*Average subsequent calving interval (days)*
3–4	78	554
5	66	515
6	77	434
7	86	447
8	70	437
9	45	458
10	41	427
11–15	69	441

In cattle, Johansson and Hansson [3] have shown a similar but smaller effect. The first calving interval was 10 days longer than the second, third, or fourth, but later calving intervals approached the length of the first again.

Repeatability of calving interval.—The correlation between one calving interval and the next for the same cow gives an indication of the extent to which this character is a permanent trait of the cow. That is to say, the repeatability of a character shows how much the character is influenced by the genotype and early environment of the cow (including maternal

influences) rather than by changes in weather, feeding, and management from one year to the next.

The calving intervals were arranged in 340 pairs being successive intervals of the same cow. The correlation between first and second interval was 0·09. When the correlation was calculated within years to eliminate the year effect demonstrated above, r was reduced to −0·08. These figures are not significantly different from each other or from zero. Asker *et al.* [4] obtained a repeatability of 0·05 for Egyptian buffaloes.

It appears that calving interval is almost entirely under the control of management (as indicated by the annual improvement) and it can have little or no genetic component.

The same thing has been shown for cattle. Johansson and Hansson [3] obtained an intra-cow correlation of 0·036 for the first five complete records of 301 cows. Asdell [5] quotes 0·07 as the repeatability of calving interval obtained during work in progress at the New Jersey Agricultural Experiment Station.

Environmental Effects on Milk Yield

Length of lactation.—In order to analyse the data in a single group it was first necessary to scale down the total lactation yields in order to make them comparable with the truncated 300-day yields. For this purpose all the total yields were tabulated according to length of lactation; in addition all yields from 300-day lactations were included for lactations lasting up to 310 days in length. The results are shown in Table 3.

TABLE 3. *Effect of Lactation Length on Milk Yield*

Lactation length (days)	*Number of records*	*Average milk yield (gallons)*
191–210	2	277
211–230	14	401
231–250	16	371
251–270	28	399
271–290	23	431
291–310	62	493
311–330	23	458
331–350	25	508
351–370	22	492
371–390	13	498
391–410	10	446
411–430	10	511
431–450	14	586
451–470	4	610
471–490	3	692
491–511	5	591

From these figures the regression of milk yield on lactation length was calculated as 0·969 gallon per day. In other words, for each increase in lactation length by 1 day milk yield increases by 1 gallon. Therefore the total lactations were corrected to 300 days by subtracting 1 gallon for

each day above 300. It must be emphasized that this correction can only be used to adjust lactations longer than 300 days. If a lactation lasts less than 300 days then the actual yield is the 300-day yield without correction.

Year of Record. All available lactations were lumped together, independent of age or lactation number, according to the calendar year in which they commenced. The results are shown in Table 4.

TABLE 4. *Average Milk Yield by Years*

Year	*Number of records*	*Total days in milk*	*300-day yield (gal.)*
1947	27	398	441
1948	139	343	417
1949	187	312	423
1950	206	304	445
1951	176	285	462
1947–51	735	312	438

There has been a slight increase in yield each year since 1948 but not sufficient to require correction or to necessitate making further analyses within years. More striking has been the decline in total lactation length. This is clearly complementary to the decline in calving interval—latterly the cows have been got in calf earlier in the lactation.

Dry period.—To determine the effect of the length of the preceding dry period on milk production in the subsequent lactation all records were grouped according to length of dry period (with a class interval of 50 days) and the corresponding milk yields averaged. The results are shown in Table 5.

TABLE 5. *Effect of Length of Dry Period on Milk Yield in Succeeding Lactation*

Dry period (days)	*Number of records*	*Lactation length (days)*	*300-day milk yield (gal.)*
–> 99	57	302	470
100–149	129	283	443
150–199	65	290	449
200–249	48	302	459
250–299	57	314	457
300 –>	35	284	438

It might be concluded that dry period length does not have any important or consistent effect on milk yield or lactation length, but Johansson and Hansson [3] have shown that such a conclusion is not justifiable from lumped data. Dry period length has a fairly high repeatability (0·26), and there is a negative correlation between preceding dry period length and yield, i.e. poor milkers tend to have long dry periods and vice versa. On the other hand, for successive lactations of the same cow,

there is a positive correlation between dry period length and yield. If these two effects are both present the lumping of data from different lactations and different cows may conceal them.

In Johansson and Hansson's material most of the dry periods were less than 100 days; in ours most were above 100 days. In view of this long dry period it seemed less likely that variations were affecting milk yield and we decided to accept the result at its face value rather than embark on the difficult task of trying to estimate the effect of dry period on yield, within cows. This decision is supported by Sanders's results with cattle [6], where the effect of length of dry period on milk yield was large below 100 days but small above 100 days.

Month of calving.—The effect of month of calving on milk yield is shown in Table 6.

TABLE 6. *Effect of Month of Calving on Milk Yield*

Month of calving	*Number of records*	*Total days in milk*	*300-day milk yield (gal.)*
January	18	296	546
February	8	311	466
March	13	352	482
April	16	317	390
May	57	319	424
June	77	307	428
July	151	302	419
August	109	302	441
September	104	290	420
October	90	308	421
November	52	334	473
December	30	353	473
November–March	121	333	484
April–October	604	303	424

Milk yield is conspicuously higher for lactations starting in winter, the cool season, than for those starting in summer. This difference is clearly associated with the comparative inefficiency of the buffalo in controlling its body temperature. In hot weather daily wallowing or spraying with water is essential for its well-being.

To allow for this seasonal effect the records were divided into two groups, namely November to March and April to October. The average 300-day milk yields were 484 and 424 gallons respectively. Yields for the first group were corrected by multiplying by $484/424 = 0{\cdot}88$.

Age at calving.—The first question to decide was whether to calculate correction factors based on age or on lactation number. The advantage of the former was that the age of nearly all animals was known whereas only first lactations were noted as such. It was possible to pick out most of the second lactations because the date of first calving was usually given. Many of the later lactations, and especially the fourth and later, could only be estimated from the age at calving.

However, a preliminary analysis showed that lactation number and

not age was the important factor influencing yield. Table 7 shows that for any one lactation, age has little or no effect on yield.

The number of all later lactations was estimated where necessary from the date of first calving and the age of calving. Correction factors were then calculated by the paired lactation method. All animals having first

TABLE 7. *Effect of Age of Calving within Lactation on Milk Yield*

Lactation number	*Age at calving*	*Number of records*	*Milk yield (gallons)*
1	up to 3 yrs. 11 mths.	74	398
1	4 yrs. to 4 yrs. 11 mths.	72	394
1	5 yrs. and over	4	378
2	up to 4 yrs. 11 mths.	14	439
2	5 yrs. to 5 yrs. 11 mths.	102	423
2	6 yrs. and over	30	428

and second lactations were tabulated and the mean for each lactation calculated. Their ratio gives the amount by which first lactations have to be multiplied to make them equivalent to second lactations. This process was repeated for second and third and for third and fourth lactations. It was taken no further because of the increasing inaccuracy of the assignment of lactation numbers and because of the smallness of the difference between third and fourth lactations. The results are shown in Table 8.

TABLE 8. *Effect of Lactation Number on Milk Yield*

Lactations paired	*Number of pairs*	*Mean of first of pair (gal.)*	*Mean of second of pair (gal.)*	*Ratio*	*Correction factor*
1 and 2	94	395	441	1·113	1·20
2 and 3	89	413	446	1·080	1·08
3 and 4	74	429	446	1·040	..

On the basis of these results it was decided to correct all first lactations by multiplying by 1·20 and all second lactations by 1·08. Later lactations were uncorrected. These figures are quite similar to those applicable to European dairy cattle. Although the increase from first to second lactation is rather more and that from second to third is rather less, the final correction factors are almost identical with those which can be calculated from the figures given for the British Friesian in the Report of the Bureau of Records of the Milk Marketing Board of England and Wales, 1946–7.

Working on Italian buffalo, Maymone [7, 8] showed similar age effects. Yield increased by 11 per cent. from first to second lactations and again by 11 per cent. from second to third lactations. The yield remained fairly constant during the third to fifth lactations and then slowly declined.

These age effects are more similar to those found for European cattle than to those for zebu cattle. Stonaker [9] studying Red Sindhis in India and Robertson [10] on White Fulani in Nigeria showed that there was little difference between first and second lactation milk yields. Sikka [11], working on Sahiwals, found an 8 per cent. increase from first to second lactation and little thereafter.

Examination of Table 8 may give the impression that second calvers kept for a third lactation, and third calvers kept for a fourth lactation, give less milk than average. This is not a fair deduction. The discrepancy is due to the fact that each of the groups of paired lactations refers to a different sample of animals in the same year and not to the same animals in different years.

Repeatability of Milk Yield

The correlation between successive yields of the same cow is an important practical and theoretical index. It shows to what extent the first lactation is an index of later yields. The higher the correlation the more accurate culling on first lactations will be. It also gives an upper limit to the heritability since the repeatability includes all the genetic variance together with the variance due to early treatment.

TABLE 9. *Correlation between Successive Lactations*

Lactations	*Number of pairs*	*Correlation coefficient*
1 and 2	94	0·316
2 and 3	89	0·188
3 and 4	74	0·192
4 and 5	42	0·602
5 and 6	32	0·475
Later	45	0·495
Total	376	Weighted mean 0·328

The correlation between successive yields, independent of age, and uncorrected for lactation number, was 0·384 (390 D.F.). This is close to the only other published figure for repeatability of milk yield in buffaloes, viz. 0·37 obtained by Asker *et al.* [4]. It is rather smaller than most of the figures obtained for cattle in Europe. For instance, Robertson and Rendel (unpublished) found a repeatability of 0·53 for dairy breeds in England; Mahadevan [12], 0·46 for the Ayrshire; Johansson and Hansson [3], 0·42 for Swedish Red and White cattle.

When the calculation was made within lactations practically the same figure was obtained (0·368 with 370 D.F.). The figures for individual lactations, however, varied considerably (see Table 9).

The low correlations for the first three lactations compared with later lactations can be explained on the basis of the arrangement of the cows in three groups. They may be transferred to another group on the basis of their yield during any of the first three lactations. Some of the pairs of lactations will therefore take place under different environmental

conditions. No transfers occur after the third lactations. It may therefore be that the mean correlation between pairs of lactations after the third gives a truer figure for repeatability. The mean, 0·53, is in close agreement with the figure for British cattle.

Heritability of Milk Yield

The heritability (h^2) of a character is one of the most important genetic parameters since it indicates the proportion of the total variation which is due to the average effect of genes, i.e. which will respond to selection. In discussing figures for heritability it is necessary to specify the conditions under which it is measured, since the value of h^2 is affected both by changes in the additive genetic variance (σ_g^2) and in the variance due to other causes (σ_e^2):

$$h^2 = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_e^2}.$$

Heritability is measured by the resemblance between relatives. In this material it was measured in two ways—from the correlation between dams and daughters and from the resemblance between paternal half-sisters.

TABLE 10. *Variance Within and Between Sires, First Corrected Yield in Gallons*

Source	*Degrees of freedom*	*Mean square*	*Variance ratio*
Total . . .	277	14,630	..
Between sires . .	26	20,640	1·47
Within sires . .	251	14,010	

The most satisfactory measure of milk yield is the first lactation yield, because this has been subject to the minimum of selection. Later lactations will only be available from animals not culled after the first. A selected sample of dams does not matter provided the offspring form a random group. In this material insufficient first lactations were available since the animals were at different ages during the years 1947–51. Furthermore, dams and daughters could not both have their first lactations during these years. It was therefore decided to correct all lactations for age (and month of calving) according to the correction factors calculated, and to use the first available lactation for calculating the heritability. For 278 animals (mean corrected yield 442 gallons) the sire was known. From these the heritability could be calculated from the analysis of the variance between and within sires. Since half-sibs are only 25 per cent. related the variance between sires (σ_b^2) must be multiplied by 4 to give the genetic variance. The heritability is then $4\sigma_b^2/\sigma_w^2 + \sigma_b^2$ where σ_w^2 = variance within sires. The analysis of variance is shown in Table 10.

The difference between sires is not quite significant at the 5 per cent. level. The heritability calculated from these figures is 0·18 ± 0·16.

Owing to the small numbers it is not significantly different from zero but it gives support to the estimate of 0·24 by Asker *et al.* [4], which was based on only 44 degrees of freedom. It is no smaller than some of the estimates of heritability of milk yield in cattle, e.g. Mason and Robertson (unpublished): 0·13, Lush and Strauss [13]: 0·14; but usually the estimates are higher, e.g. Robertson and Rendel (unpublished): 0·43, Mahadevan [12]: 0·31, Johansson and Hansson [3]: 0·38.

In fact it may be higher than the true figure. If Nili bulls are only used in the Nili group and Ravi bulls in the two Ravi groups then differences between sires in the yield of their daughters will include any difference in management between the Nili and Ravi groups.

TABLE 11. *Correlation between Yields of Dams and Daughters*

	Degrees of freedom	*Regression of daughters on dams*	*Heritability*
Total . . .	79	−0·09	−0·18±0·21
Within sires . .	57	−0·05	−0·10±0·25

In order to reduce the environmental variance the first two available yields were averaged and the heritability of this average was calculated. The result was $h^2 = 0{\cdot}26 \pm 0{\cdot}20$. The genetic variance remained the same (the coefficient of variation between bulls was 5·9 per cent. in both cases) but the variation within bulls—the environmental variation—was reduced. According to Lush's formula the heritability of the mean of m lactations should be $h_m^2 = mh^2/1+(m-1)r$ where r is the repeatability. If we insert $m = 2$, $h^2 = 0{\cdot}18$, and $r = 0{\cdot}38$, h_m^2 should be 0·26 precisely as found.

Heritability was also calculated from the correlation of the first available corrected yield of daughters and dams, by doubling the regression of daughters' yield on dams' yield. The regression was calculated within sires in order to eliminate any bias due to departure from random mating. The result is shown in Table 11.

A negative heritability is, of course, impossible but the high standard error shows that this negative value may well be due to the smallness of the sample. There is another possible explanation. Since the yields of dams and daughters compared are at least four lactations apart some at least will be in different groups at the time of these lactations. In particular, high-yielding daughters from poor cows will be put in the best-managed group and vice versa. The differences between dams and daughters will be exaggerated and if this applies to a sufficient number of pairs the result will be a negative correlation between them.

Discussion

This paper does not claim to be more than a preliminary study of the subject, since it is based on the results from only one herd over the course of 5 years. It does, however, suggest that until more extensive

records can be analysed, the behaviour of the buffalo in Pakistan can be compared in many respects with that of the dairy cow in temperate climates.

Admittedly the age at first calving is rather higher and, naturally, seasonal effects on reproduction and on milk yield are different from those in western Europe. But the length of the calving interval and the possibility of its control by management rather than by breeding are very similar to the state of affairs in temperate-climate cattle breeding.

The effect of age on yield is more similar to the effect demonstrated on European cattle than on zebu cattle in West Africa [10] or in India [9] where yield increased little between first and second lactations.

The figures for heritability of yield cannot be given much weight but the more reliable of the two estimates is similar to the European and American results with cattle. Probably the important conclusions from this part of the study are (1) that to be reliable heritability estimates must be based on many observations—at least 1,000 dam/daughter pairs for instance; (2) that differences between herds or between differently treated groups within herds must be allowed for; (3) that the precise character measured, the animal population in which it is studied and the environmental conditions (including feeding and management) must all be taken into account before different estimates of heritability are compared.

If we assume that the genetic situation is in fact very much as in cattle then the breeding policy recommended for this herd is as follows. To begin with, the low heritability of milk yield indicates that most of the variation is due to influences other than those which are additively genetic in effect. Therefore great improvement should be possible by attention to feeding and management. For instance, an attempt should be made to lower the average age at first calving from 4 years to 3 years. This should have no detrimental effect on yield and it will have the advantage of reducing the non-productive period in the life of each cow. It will also reduce the generation interval and so increase the genetic improvement per year for the same rate of genetic improvement per generation.

Cows should be selected on their first lactation yields or even on the yield in the first 70 days of their first lactation. This herd is almost large enough to use the progeny-testing system recommended by Robertson and Rendel [14]. Bulls should be bred from the best cows and progeny-tested on the basis of 10–15 daughters. Later bulls should be bred from the best tested bulls.

The division of the herd into three groups and the parallel selection for type will complicate the system. If milk yield is the most important attribute it might be advantageous to scrap the three-group system and restrict the type selection to the selection of bulls for testing.

Summary

Records were available for 754 lactations of 338 buffalo cows which calved at Bahadurnagar Farm, Montgomery, west Punjab, during the years 1947–51.

The average age at first calving was 3 years 11 months. Calvings were most frequent in July; between January and April they were at a minimum.

The average interval between consecutive calvings was 467 days. It declined rapidly during the five years of this study.

The repeatability of calving interval was 0·09.

The average milk yield in a 300-day lactation was 438 gallons. Yield was lower for summer calvings (April to October) than for winter calvings. It increased by 11 per cent. between first and second lactations and by 8 per cent. between second and third. Year of record and length of dry period had little effect.

The repeatability of 300-day milk yield within lactations was 0·37.

The heritability of the first available 300-day yield, corrected for lactation number and season of calving, was $0{\cdot}18 \pm 0{\cdot}16$. This was based on 278 daughters of 27 bulls. The heritability of the average of two lactations was $0{\cdot}26 \pm 0{\cdot}20$.

Acknowledgements.—The writers wish to express their thanks to S. M. A. Shah, Esq., Director of the Department of Animal Husbandry, Punjab, for kindly furnishing the data; to Professor C. H. Waddington, Director of the Institute of Animal Genetics, Edinburgh, for supplying facilities for carrying out this study; and to Dr. Alan Robertson for his valuable advice.

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(*Received 12 March 1954*)

COTTON BREEDING IN THE SUDAN

PART III. AMERICAN UPLAND COTTON

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WORK on Egyptian cotton was described in Parts I and II of the series (this J., 1954, **22**, 67 and 81). The American Upland cotton industry of the Sudan was established on an early importation of Nyasaland Upland, which itself derived from Floradora, a derivative of Allen's Long Staple. This Sudan race of Nyasaland Upland became known as Pump Scheme Strain. This strain, though very heterogeneous both in vegetative and lint characters, span well and had a ready market. Up till 1930 Pump Scheme Strain was almost the only variety of American cotton grown commercially in the Sudan.

By the beginning of the war, Pump Scheme Strain was still the commercial crop of Kordofan, XA1129 (ex Meade) was established commercially throughout the Dongola area, '513' bred from Punjab 'Early Strain' was being grown throughout Berber (except for some 5,000 acres of Wilds 11 at Zeidab), 511D (ex Uganda SG85) was grown in western Equatoria and XA129, a selection from Pump Scheme Strain, in eastern Equatoria. During the war years, American cotton production fell sharply in the Sudan in favour of food crops.

Blackarm Resistance

The methods used in breeding for blackarm resistance in Upland cottons have followed closely on those already discussed under Egyptian cotton, except for small modifications introduced because the phenotypic expression of the main B genes is less clear-cut on an Upland background. Backcrossing does not have to be carried so far in Uplands as in Sakels because Uplands are so much lower in quality that minute differences in lint characters are of no significance.

From the beginning it was apparent that blackarm resistance in American Upland cottons hinges on the presence of gene B_2. Where high levels of resistance have been built up by natural selection, B_2 may be accompanied by a second major gene (usually B_3, more rarely B_1) and fortified by a complex of minor genes. Early work was devoted to studying the inheritance of resistance in inter-Upland crosses involving B_1 and B_2 [23], although work on B_1 was soon discontinued because of its close linkage (or possibly pleiotropy) with d_a, one of a pair of duplicate genes controlling 'Dwarf-bunched' [48]. The second duplicate gene d_b is present in most strains of Upland though absent in *barbadense*.

A technique was evolved for transferring B_3 to Upland strains [6], and a range of Uplands carrying B_2 and B_2+B_3 was synthesized.

Of the varieties already being grown commercially in the Sudan when blackarm-resistance work started, two were found to carry B_2: 511D and

[Empire Journ. of Exper. Agric., Vol. 22, No. 87, 1954.]

'513'. Pump Scheme Strain and its derivative XA129 were both fully susceptible, as was XA1129. Pump Scheme did at this time carry some 5 per cent. of B_2 plants (doubtless derived from *punctatum* out-crosses) but these could not spread through the crop under the impact of blackarm because the Kordofan seed supply was renewed at intervals from irrigated areas in the arid north where blackarm was negligible.

BAR.SP84 and its derivatives.—In 1941 a small quantity of seed of Uganda SP84R was obtained. The variety was found to be heterogeneous for B_2. It was rendered homozygous by line selection [6] and issued commercially as BAR.SP84. The susceptible component was extracted and given the number SUS7/2.

BAR.SP84 and SUS7/2 were included in a replicated variety test at Kadugli, Kordofan Province, in 1943–4. Blackarm caused considerable crop loss in the susceptible type, and BAR.SP84 outyielded it by 64 per cent. [6]. Over a series of years, BAR.SP84 outyielded Pump Scheme and, although its lint is slightly less mature and somewhat weaker, it has usually been valued rather above Pump Scheme Strain by brokers [49]. By 1948 BAR.SP84 had replaced Pump Scheme Strain throughout Kordofan. It also replaced 511D in Equatoria and '513' and XA1129 in the north in due course.

Meanwhile, in 1942, 258 plants were taken at random from a bulk propagation plot of BAR.SP84. These were sown at Shambat, plentifully interspersed with controls of the parent bulk, as progeny rows. These rows were first examined for lint length and uniformity. Rows showing rather better length than BAR.SP84 were passed, but extreme types and inferior types were discarded. The rows which had passed on lint length were reselected for high ginning out-turn and then for 'feel' and strength. Fifteen progenies passed all tests and these were bulked as BAR7/3 [45]. On test against BAR.SP84, BAR7/3 has maintained its improved ginning out-turn and quality and it has, accordingly, been expanded to a commercial wave and this (1952–3) season half of the Kordofan crop is under this type.

Immediately BAR.SP84 had been made, the process of transferring B_3 to it from a *punctatum* cotton was begun, and by 1948 an SP84 type homozygous for both B_2 and B_3 was released for trial under the strain number BAR7/8. Tested against BAR.SP84, the new type showed the value of the additional resistance conferred by B_3. The lint of BAR7/8 proved somewhat shorter than BAR.SP84 and it was decided to improve both this and the yielding capacity before expanding the new strain. Accordingly, 430 plants of BAR7/8 were selected by M. F. Rose and others. Only plants showing good robust growth were chosen. The seed cotton from these was examined for quality and measurable characters by M. F. Rose. Forty-six plants passed his tests and these were grown in progeny rows in 1950–1 by K. C. Barlow, who bulked the best of them under the number BAR7/8.1. Self-bred seed of these bulked progenies was immediately sown out of season near Shambat and this was followed by two waves of expansion, one in-season and the other winter sown, at Shambat itself. The new type is now (1952–3) growing on 240 acres in Kordofan and it was included in all four of the Kordofan

variety tests for the first time this season. Lint yields from these trials are given in Table 6; they show clearly the value of this breeding work.

Meanwhile, within one of the BAR7/8.1 propagation areas sown at Shambat, 850 plants were selected, each with fifteen or more green bolls (the modal number of bolls counted on 2,000 plants being fifteen at this time.) Laboratory analysis on these 850 plants was directed towards improvement of length, regularity, and strength, and on these characters the number was reduced to 194. The seed of these was then sent to Kadugli where it was grown in progeny rows against BAR7/8.1 controls. This final filtering is directed towards further improvement of yield and quality.

TABLE 6. *Lint Yields from Four Replicated Trials in Kordofan, 1952–3 (lb./acre)*

Variety	*Kadugli*	*Talodi*	*Lagowa*	*Habeila*	*Average*
BAR7/8.1 . . .	470·5	229·9	238·4	232·1	292·7
BAR7/8 . . .	404·5	242·4	240·6	264·7	288·1
BAR7/3 . . .	308·9	188·8	211·2	231·7	235·2
BAR.SP84 . .	309·8	187·0	196·4	195·5	222·2
P.S.S. . . .	278·1	167·4	187·0	200·0	208·1

Finally, at Shambat, the blackarm-resistance intensifier B_{6m} is being transferred from Sakel[1] to BAR7/8.1. This should make the type effectively immune even under the worst conditions of blackarm infection.

XA129 and its derivatives.—Although BAR.SP84 yielded better than XA129 under Equatoria conditions, it was thought that this superiority lay solely in the presence in it of B_2 (XA129 carries no resistance). Since XA129 had suited Equatoria so well it was decided to add resistance to it. B_2 and B_3 were transferred to it separately, the latter gene being taken from a synthetic Sakel, as this seemed better than going back to the original *punctatum* donor parent. In each case, only five crosses to the recurrent parent were made before selfing out. The B_2 material, bulked under the number BAR11/5, was tested by the Senior Research Officer, at Yambio, against a number of varieties including BAR.SP84 and BAR7/8. It proved so promising, both in yield and especially in quality, that the strain is now being expanded at Yambio with a view to replacing BAR.SP84. A successor strain (BAR11/7) carrying both resistance genes has now been made and to this B_{6m} is being added.

One possible advantage of the XA129 derivatives is that they are of semi-cluster type so that they may well prove valuable for mechanical picking.

Uganda BP52 derivatives.—Uganda BP52 originally lacked any major blackarm genes, though strains of it bred in Uganda are now available carrying a proportion of B_2 plants. In 1942 crosses were made at Shambat between BP52 and Uplands carrying B_2 and B_3. Homozygous B_2 types were selfed out from third and from fifth backcross material

[1] This gene was originally transferred from *G. arboreum* to Sakel.

and numbered BAR12/1 and BAR12/3 respectively. Neither type proved particularly suitable for Sudan conditions and neither had the quality associated with modern BP52 stocks. The attempt to transfer B_3 to BP52 failed, and although it was repeated it again failed. It was not possible to detect the presence of B_3 in the backcrosses.

In 1949 a fresh breeding line of BP52 was obtained from Namulonge, Uganda. This contained about 75 per cent. of B_2 plants. Progeny rows were grown and those homozygous for B_2 were bulked as BAR12/9. The susceptible plants were also bulked and given the number SUS12/8. Crosses were made between a B_3 line and SUS12/8, but again the B_3 gene was lost. For some reason, as yet unexplained, it appears impossible to transfer B_3 to Uganda BP52. In view of these repeated failures an attempt was made to increase the resistance of BAR12/9 by growing it in isolation, spraying with blackarm inoculum, roguing heavily for maximum resistance and allowing the most resistant plants to intercross freely so as to build up higher levels of minor gene resistance over and above B_2—a similar technique to that employed for leafcurl resistance breeding at Shambat. After three waves of roguing and further propagation on these lines it was found that the resistance of BAR12/9 had been increased somewhat, but there is clearly not a sufficient pool of minor genes in this type to make possible the building of high resistance around B_2. The final product of this selection work was given the number BAR12/9.3 and it is to this substrain that the intensifier B_{6m} is now being transferred.

Other Special Properties

Deciduous bracts.—Although at present the economy of the Sudan is mainly based on the Gezira, there can be little doubt that, if the country is to progress, there will come an expansion of agriculture in the less populated rainlands of the central Sudan in the 25–30 in. rainfall belt. This will mean an increasing use of mechanical cultivation and, if Upland cotton is to be the cash crop in any of these areas, it will probably have to be picked mechanically. For this reason all morphological aids to mechanical picking possessed by the cotton plant are of interest in this country.

In 1945 a mutant Upland type, 'Withering Bract', was imported from U.S.A. and the transfer of the character both to BAR.SP84 and to Sakel was undertaken. The character was shown to be due to a single recessive gene, bw, with a pleiotropic action causing leaf crumpling and also sterility to a greater or less degree. Pollen grains carrying bw appeared to have an advantage in fertilization. At a low modifier level bwbw plants were more or less sterile and had severely crumpled foliage. At a higher modifier level many of the bwbw plants were indistinguishable from normal: in such families the deleterious effects of bw were largely masked, but as a result the bracteoles failed to wither effectively [36].

Clearly the gene bw is of no value to plant breeders. Whether any other gene or genes which reduce or remove bracts can be employed without lowering yield is at present only a matter for speculation, but

it is significant that Kearney [50] showed that excision of the bracts at anthesis reduced boll-size, and the weight of seed and lint per boll.

Cluster types.—'Cluster' varieties are more easily picked mechanically by certain of the machines than varieties with sympodia of normal length. It is therefore important that a collection of such varieties, suited to Sudan conditions, should be available for trial as soon as mechanization is seriously attempted.

In BAR11/7 (XA129 carrying B_2+B_3) we are fortunate in having a semi-cluster type with fairly large bolls which should be well suited to mechanization. BAR.NT96, a 'quality' Upland bred by R. R. Anson in Kordofan, has several times thrown cluster mutants and one of these, after being reselected on quality, has been bulked as BAR20/1 and B_{6m} is being added to this. Recently a cluster mutant was found in a propagation plot of Punjab 268F and this is being bred up by M. F. Rose at Medani as a possible mechanical type suited to areas where considerable earliness is required. Like BAR20/1 this type also carries B_2.

Ginning out-turn.—Deltapine has a ginning out-turn[1] of approximately 40 per cent., but has lint of poor quality; XA129 has a ginning out-turn of about 30 per cent., has lint of good spinning quality and is well suited to conditions in Equatoria. In 1942–3 a line of investigation was started to see whether some, if not all, of the high ginning out-turn of Deltapine could be transferred to XA129 without deleteriously affecting the lint of the latter.

High ginning out-turn proved partially dominant in F_1. A first backcross consisting of 2,487 plants was grown, plentifully interspersed with random holes of Deltapine, XA129, and the F_1 of the varieties. The first two beds of the experiment were discarded because of irregularity of growth, so that the following figures are based on populations of 118 XA129 plants, 117 F_1 plants, 99 Deltapine plants, and 1,274 first backcross plants.

The XA129 controls gave a range of ginning out-turn on individual plants from 26 to 33 with a mode at 29 per cent., Deltapine ranged from 32 to 45 with a mode at 39 per cent., the F_1 ranged from 31 to 41 with a mode at 35 per cent., and the first backcross ranged from 24 to 36 with a mode at 32 per cent. There were 34 first backcross plants showing 36 per cent. ginning out-turn; these were reselected for nearness to XA129 appearance and quality, and again backcrossed to XA129 and selfed.

In the F_2 of the first backcross some plants appeared which combined lint of approximately XA129 quality with ginning out-turns of 35 to 36 per cent. These were selfed.

The second backcross F_1 yielded a few plants with XA129 quality combined with ginning out-turns up to 34 per cent. These were selfed. At this stage further work on improving the ginning out-turn of XA129 was suspended, because XA129 was being replaced by BAR.SP84 in Equatoria. But although this line of research did not, because of this replacement, have any direct practical value, it points the way for future work.

[1] Ginning out-turn is the percentage of lint produced when seed cotton is ginned.

Earliness and pest avoidance.—Wilds selections. In 1947 R. R. Anson made a number of selections for earliness in the commercial crop of Wilds 16 at Zeidab in the Northern Province. Earliness was judged by the position of the first fruiting sympodium on the main stem and all these selections had a low 'node number'. The object of selecting for earliness was to reduce the damage caused by the capsid bug *Creontiades* and by pink bollworm. Seed of Anson's selections was divided equally between Kadugli and Shambat stations where M. F. Rose and the writer, working in parallel, reselected it for low node number. The product of this work, bulked as Wilds SUS16/1 is now being expanded in Northern Province where excellent yields are being obtained from it.

Punjab 268F. The change over from Webber varieties to '513' in the Berber area in the mid-1930's more than doubled the yields in this zone [2]. '513' originated from Punjab Early Strain and these increased yields were due to its capacity for avoiding bollworm by reason of its marked earliness and rather small, rapidly hardening bolls. During the war the seed supply of '513' for Berber was lost, so a number of Punjab strains were imported in 1946 and grown at Shambat. Of these types, 268F appears the most suitable for local conditions. At Shambat it gives a heavy crop, even when bollworm damage is severe on other cottons, and its lint is of fair quality. The type has, accordingly, been bulked up and stored, so as to be available if official encouragement is given to cotton growing in the Khartoum-Berber zone.

Breeding Methods in the Sudan

Whilst the value of single-plant selection is recognized as a means of obtaining new varieties, the use of the single plant for type maintenance or for improvement within a variety is viewed with marked distrust. All the breeding methods used in the Sudan are aimed at the maintenance of the maximum variability compatible with lint quality of the accepted standards. This is achieved differently according to whether the objective is gene transference or improvement *within* an accepted type.

Gene transference.—Where a single gene is involved, varietal genetic variability is maintained by choosing a number of plants carrying the gene, in each backcross progeny. These plants are used as the male parent, and bulk crossing between them and a large population of the recurrent parent is carried out. This process is repeated for each backcross, but the importance of the size of populations used is greatest in the final crosses.

Where a number of genes are involved, as in jassid resistance, the full complement of genes can only be recovered, after selfing each hybrid generation, by careful selection of single plants. By using these as males and pollinating a large population of the recurrent parent variety with them, a fair degree of variability can be retained.

Improvement within a type.—Improvement within an accepted type is brought about by selfing a large number of plants in the variety, growing these as progeny rows against numerous controls of the type itself, and bulking together all rows showing certain desirable combinations of

improved characters. This process is called 'filtering'. The improvement of agricultural characters such as yield, quality, ginning out-turn and salt tolerance is essentially a process of building up minor gene complexes, whether these are superimposed on a major gene or not. This imposes a limitation on the value of selection in continuously self-bred material. To obviate this, Medani Station does filtering on X1730 and Domains Sakel derivatives in alternate seasons. The filtered strains from each season's work are grown in isolation at Shambat, preferably for not less than two generations (one of which is sown out of season), to enable random mating and subsequent segregation to build up still higher levels of minor genes in the characters required. Advantage is taken of this propagation period at Shambat to carry out such operations as increasing leafcurl resistance by heavy roguing. In the second wave of propagation at Shambat a large number of single plants are selected. Seed of these is grown as progeny rows at Medani in the following season and from this a second 'filter' of the strain is produced. Similarly, Kadugli Station alternates work on BAR7/8 derivatives with filtering of other types such as BAR.NT96 and BAR11/7.

It is, of course, a rather different and perhaps fortuitous application of this principle which has enabled cotton breeders in Egypt to produce agricultural improvements out of almost any inter-varietal cross. In effect they build up minor genes to the approximate maximum, by selection in a selfed line from a single plant and, later, when they intercross varieties, segregation of the separately selected gene complexes gives the possibility of finding still higher levels of expression of the characters. Varietal change is the unavoidable result of the Egyptian approach to the problem; the Sudan technique is designed to preserve varietal standards while incorporating certain specific improvements.

To sum up: breeding policy in the Sudan has consisted in surveying the exact varietal requirements of individual localities and in *making* varieties embodying these requirements; as opposed to the more usual practice of seeking varietal improvement by the selection of fortuitous differences.

Summary

Cotton breeding in the Sudan has largely been concerned with disease and pest resistance, with the overriding principle that the basic lint quality of the two Sudan Sakel varieties shall remain unchanged.

Eight major genes controlling resistance to blackarm disease (*Xanthomonas malvacearum*) have been identified in the course of investigations throughout the main species and varieties of cotton. These have all been transferred to Sudan Sakel strains: a combination of two of them (B_2 and B_3) gives high resistance and the further addition of B_{6m} confers field immunity. Commercial strains of Egyptian and American cotton carrying B_2 from *hirsutum* and B_3 from *punctatum* have been synthesized and B_{6m} is being added to these from *arboreum*. Evidence is adduced that *Xanthomonas* originated in India and the evolution of resistance in the main cotton areas of the world is discussed.

Resistance to leafcurl virus is polygenic and 'synthetic' *Xanthomonas-*

resistant Sakels are made resistant to leafcurl by culling the more susceptible plants, allowing the remainder to intercross and segregate out higher levels of minor gene resistance, and then again culling. This process, carried out on *large* populations, can give high resistance in as few as three generations.

Jassid (*Empoasca*) resistance depends on long, dense hairs on the lower surface of the leaves. Such hairiness in *G. hirsutum*, *G. barbadense*, and *G. herbaceum* is controlled by a main gene, H_1, accompanied by numerous minor genes. In *hirsutum*, modifying genes increase the length of the hairs conferred by H_1. A second gene, H_2, occurs in *G. tomentosum* and (rarely) in American Upland. H_1, with its modifier and minor gene complex, has been transferred to blackarm-leafcurl-resistant Sakel from Philippines Ferguson (*hirsutum*) and lines as hairy as Ferguson have been selfed out from the sixth Sakel backcross.

Investigations on Sudan Sakels show the value of earlier sowing (only possible with *Xanthomonas* resistance) in improving 'grade'. Work on salt tolerance is outlined as is work designed to lessen 'trash' by reducing the size of involucral bracteoles. Storm resistance is being transferred to Sakel from *G. contextum*, 4-loculed bolls are being transferred from Upland, and the number of ovules per locule is being raised by hybridization with *G. auritum*.

In transferences of lint strength from the lintless diploid, *G. thurberi*, plants of typical Sakel appearance, but with Pressley Indexes up to 10·7 compared with 8·0 for Sakel have been obtained.

The genes for 'cluster' and 'short branch' (potentially valuable for mechanical harvesting) when transferred to Sakel proved too weak to be of use. Within the Upland crop, cluster mutants have been selected for mechanized trials.

Breeding for earliness in Sakel aims at shortening the bud-formation to flowering period by hybridization with Asiatic varieties.

In the transference of bollworm resistance from *G. thurberi* and *G. armourianum* to New World cottons via synthesized hexaploids, segregates with marked resistance have been recovered.

The breeding systems used maintain maximum variability compatible with lint quality of the accepted standards. The policy is to survey varietal requirements of individual localities and to synthesize varieties embodying these requirements, as opposed to the more usual practice of seeking varietal improvement by selecting fortuitous differences.

Key to Main Sudan Varieties Mentioned

'Egyptian'-type Cottons

Domains Sakel ('S' cotton) derivatives

Domains Sakel	Originally imported from Egypt, now acclimatized.
BAR14/1	Domains Sakel carrying B_2.
BAR14/7	Domains Sakel carrying B_2 (later backcross than BAR14/1).
BLR14/16	Leafcurl-resistant filter of BAR14/7.

BAR14/21	Domains Sakel carrying B_2 and B_3.
BLR14/25	Partially leafcurl-resistant filter of BAR14/21.
BLR14/25.1	BLR14/25 filtered for lint quality, G.O.T. and leaf-curl resistance.
BLR14/25.2	BLR14/25.1 refiltered for leafcurl resistance.
BLJR14/29	Domains Sakel carrying $B_2+B_3+H_1$+leafcurl resistance.
NT2	Sakel selection intermediate between 'S' and 'L' quality.

X1730 ('L' cotton) derivatives

X1730A	Commercial type of Sakel origin rather coarser than 'S' cotton.
BAR1730L	X1730A carrying B_2.
BAR1730L.1	First filter of BAR1730L.
BAR4/11	X1730A carrying B_2 and B_3.
BAR4/16	X1730A carrying B_2 and B_3 (later backcross than BAR4/11).
BAR5/6	X1730A carrying $B_2+B_3+R_2^{RS}$.

Upland-type Cottons

XA129 derivatives

XA129	Selected from Pump Scheme Strain by H. E. King.
BAR11/5	XA129 carrying B_2.
BAR11/6	XA129 carrying B_3.
BAR11/7	XA129 carrying B_2 and B_3.

Uganda SP84 derivatives

BAR.SP84	The B_2 component selected from SP84.
SUS7/2	The b_2 component selected from SP84.
BAR7/3	First filter of BAR.SP84 for quality and G.O.T.
BAR7/8	BAR.SP84 carrying B_2 and B_3.
BAR7/8.1	First filter of BAR7/8 for improved quality.

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(For References Nos. 1–26, see the issue for January 1954, No. 85, p. 79; for Nos. 27–47, see that for April 1954, No. 86, p. 91.)

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(*Received 18 August 1953*)

THE EFFECT OF SEED DRESSINGS CONTAINING AN ORGANO-MERCURIAL AND GAMMA BHC ON GERMINATION TESTS OF OATS

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THE dusting of cereal seed with organo-mercurial fungicides as a protection against smut, leaf stripe, and other diseases has long been practised. Seed treated in this way may, in certain circumstances, give rise to abnormal seedlings, but it was shown by Brett and Dillon Weston [1] that there is no loss of vitality in seed of high germination that is dry and physically sound, provided the recommended dosage is not exceeded. They found that in good conditions such seed can be stored for over a year after treatment without deterioration. The phytocidal effects of the fungicide were reported to be most evident in wheat and least in barley, with oats intermediate, but Lafferty [2] later found oats more resistant to such injury than the other cereals.

More recently there have come on the market cereal seed dressings that contain a mixture of organo-mercurial with gamma benzene hexachloride, thus adding to the fungicide an insecticide which is effective against wireworm [3]. It was soon noticed by the official seed-testing stations that abnormal seedlings were liable to appear in germination tests of seed that had been dusted with this mixture, sometimes to such an extent as seriously to reduce the reported germination percentage. The characteristic abnormal symptoms were a thickened coleoptile and short peg-like roots, similar to those known to develop from seed overdressed with an organo-mercurial alone, but occurring more frequently and with the symptoms exaggerated. It was claimed, however, that treated seed germinated relatively better in the field than in laboratory tests on sand or filter paper and was not adversely affected by storage for 12 months [4].

The abnormalities due to the mixed dust were observed most frequently in barley and wheat, but the Scottish Seed Testing Station is more particularly interested in oats and the following is an account of an investigation that was undertaken in consequence.

Materials and Methods

The seed used was taken from crops grown on the station farm at East Craigs and was harvested and threshed by hand. No moisture determinations were made, but the seed was well dried. Seed of twelve varieties was taken from the 1950 crop and of nine varieties from the 1952 crop.

The seed dressing used was a standard proprietary brand containing 1 per cent. mercury and 20 per cent. gamma BHC and was applied at the recommended dosage of 2 ounces per bushel.

[Empire Journ. of Exper. Agric., Vol. 22, No. 87, 1954.]

Germination tests were carried out on sand and on a mixture of soil, peat, and sand; for convenience the latter is referred to in this paper as soil. For each test 200 seeds were taken, laid on the medium and lightly pressed down. As far as possible the temperature was kept between 12° C. and 15° C. Tests usually finished in 7 days, but a further 3 days were allowed if germination was slow; the results therefore represent the maximum germination capacities.

Normal and abnormal seedlings were counted separately and the latter were subdivided into seedlings with thickened coleoptiles and seedlings with unthickened coleoptiles. The latter were mostly seedlings without roots, a type of abnormality that is well known to seed analysts and which is usually described as 'plumular growth'. The numbers were expressed as percentages of the number of seeds sown.

Experimental Results

A portion of the seed of each variety that was harvested in 1950 was dusted in November of that year and the rest left untreated as a control. Germination tests of each variety were set up on soil and on sand at intervals until November 1951, the seed in the meantime being stored in envelopes in the laboratory. No differences were found between varieties; each of the twelve varieties was therefore treated as a replicate and the results are summarized in Table 1.

TABLE 1. *Differences in Germination between Seed Treated with Organomercurial gamma BHC and Untreated Seed*

	Mean differences (treated minus *untreated) of seed germinated in soil*			*Mean differences (treated* minus *untreated) of seed germinated in sand*		
Date of sowing[1]	% *normal seedlings*	% *thickened abnormals*	% *unthickened abnormals*	% *normal seedlings*	% *thickened abnormals*	% *unthickened abnormals*
Nov. 1950	−0·08	0·00	−0·16	−0·33	0·00	+0·04
Dec. 1950	+0·04	0·00	−0·04	+0·08	0·00	+0·12
Jan. 1951	−0·50	+0·08	+0·54	+0·17	+0·17	−0·04
Feb. 1951	−0·25	0·00	+0·25	−0·55	0·00	+0·42
Mar. 1951	−0·21	+0·25	0·00	−0·58	+0·13	+0·17
Apr. 1951	−0·38	+0·21	+0·16	−0·38	+0·42•	+0·25
June 1951	−0·68	+0·25	−0·12	−0·42	+0·50	−0·17
Aug. 1951	−0·30	0·00	+0·08	−0·88	+0·54•	−0·13
Oct. 1951	−0·58	+0·08	+0·29	−1·21	+0·20	+0·42
Nov. 1951	−0·38	+0·25•	+0·12	−0·38	+0·46•	+0·04
All tests	−0·32†	+0·11‡	+0·11	−0·45‡	+0·24‡	+0·11

[1] Seed was treated in November 1950. • Significant, $P < 0{\cdot}05$. † Significant, $P < 0{\cdot}01$. ‡ Significant, $P < 0{\cdot}001$.

Other differences not statistically significant.

Taken over all there was a significant decrease, more marked on sand than on soil, in the percentage of normal seedlings produced by treated seed. The difference, however, was small; it was never large enough at any one test to be detectable as significant. Statistical significance emerged only when all tests were taken together.

The percentage of thickened abnormals was significantly greater in treated than in untreated seed and again the difference was more marked on sand than on soil. In addition to showing significant differences in all tests taken together, the difference on sand was significant on three occasions and on soil once.

No significant differences, either in separate tests or in all tests together, were found in the number of unthickened abnormals. This is in accordance with the general experience that this type of abnormality occurs in germination tests irrespective of dressing.

Table 1 shows a tendency for the number of normal seedlings to decrease and the number of thickened abnormals to increase with increase in length of time elapsing between treating and sowing. After a year's storage, however, the effect of treatment was too small to be of any practical importance.

Exact records were not kept at the time, but in the course of these germination tests it became evident that most, if not all, of the abnormal seedlings with thickened coleoptiles developed from groats, i.e. caryopses that had become separated from their enclosing lemmas and pales in threshing. This indication that only groats may be susceptible to the harmful effect of the dressing conforms to Lafferty's finding [2] for organo-mercurial dusts and was followed up by taking seeds from the untreated portion of each variety and removing the husks. Half the groats were dusted with the same amount of dressing as they would have received in their husks and the other half left untreated as a control. From each variety one germination test was immediately set up with treated groats and one with untreated groats, both on sand.

The results can be summarized as follows:

	Mean difference	*Significance*
Percentage normal seedlings	−1·30	Sig. $P < 0{\cdot}05$
,, thickened abnormals	+1·58	Sig. $P < 0{\cdot}01$
,, unthickened abnormals	−0·75	Not sig. $P > 0{\cdot}2$

Even though the groats were tested immediately after dusting, the differences between treated and untreated seeds were greater than anything recorded in Table 1, but were still not very serious.

All groats were removed from samples of the nine varieties harvested in 1952. Half of this unhulled seed was dusted and the remainder left as a control. Two germination tests, one of treated and one of untreated seed, were immediately set up on sand from each variety. Only one seedling with a thickened coleoptile developed in these tests, which can be summarized as follows:

	Mean difference	*Significance*
Percentage normal seedlings	0·00	Not sig.
,, thickened abnormals	+0·06	Not sig.

Conclusions

The injurious effect of dusting oats with a mixture of organo-mercurial and gamma BHC, as seen in germination tests, is statistically significant, but too slight to be of any practical importance. The lemmas and pales

have a protective influence and the harmful effect is almost, if not completely, confined to the groats.

The number of abnormal seedlings tends to increase the longer the seed is stored after dusting, but even after a year the effect in good storage conditions was still of no practical significance.

These conclusions were drawn from experiments with seed well harvested, adequately dried, and treated with the recommended dose, and are not necessarily applicable in other circumstances.

The number of abnormal seedlings is greater with sand than with soil as a germinating medium. It is reasonable to assume that this is due to absorption of the toxic principle by the soil colloids, but no attempt was made to elucidate this point. As the seed was always laid on the surface, depth of sowing certainly had nothing to do with it.

Summary

Seed oats treated with a mixture of organo-mercurial fungicide and gamma BHC are liable to show abnormal seedlings in germination tests. These abnormal seedlings occur in small numbers only; their frequency is influenced by the germinating medium used and almost all of them develop from groats.

Acknowledgements are due to Miss I. M. C. Kay and to Mr. R. D. Seaton for assistance in carrying out the germination tests.

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(*Received 11 February 1954*)

CASTRATION AND DOCKING OF LAMBS: USE OF THE RUBBER-RING LIGATURE TECHNIQUE AT DIFFERENT AGES

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A COMPARISON of the rubber-ring ligature and crushing techniques for castrating lambs was carried out on the Leeds University Farm in 1952 [1]. Thirty-four lambs were castrated by each method at an age of 3–5 weeks, the lambs being out of Half-bred and Clun ewes, sired by Suffolk rams. Little difference was found in the subsequent progress and performance of the two groups, but the use of the rubber-ring ligature (Elastrator) seemingly involved the animal in more discomfort immediately after the operation and to a limited extent retarded rate of live-weight gain. According to other experience the discomfort described could have been avoided by castration with the rubber-ring ligature at

TABLE 1. *Composition of the Ewe Flock when the Rams were turned in on 6 October 1952*

	Half-bred		*Clun*	
	Mated as ewe lambs in 1950 and proved pregnant	*Mated first as shearlings in 1951*	*Mated as ewe lambs in 1950 and proved pregnant*	*Mated first as shearlings in 1951*
Mated to Ram A	7	15	4	18
Mated to Ram B	8	14	4	17
Total . .	15	29	8	35

an earlier age (within a week of birth). In view of this a further experiment has now been completed, using the 1953 crop of lambs from the same flock. One group of lambs was castrated within a week of birth and another group at ages from 21 to 30 days, the Elastrator being employed to effect castration in all cases. Full records were kept of behaviour and subsequent performance until the lambs were sold fat at an average live weight of 83 lb.

At the same time the Elastrator was employed as a means of docking the lambs. Some experience of this method had been gained in 1952, when 136 lambs were so docked at ages from 16 to 39 days, and the impression was gained that lambs docked by the rubber-ring ligature suffered slightly more acute initial discomfort than lambs which were only castrated. In fact, similar symptoms were exhibited by lambs which were docked and those which were both castrated and docked on the same occasion. It was felt desirable to make more precise observations

[Empire Journ. of Exper. Agric., Vol. 22, No. 87, 1954.]

on the degree and duration of the symptoms over a wider range of age. Accordingly in 1953 the lambs, male and female, were divided into two groups, one being docked within a week of birth and the other at ages from 21 to 30 days, as in the case of castration. Similarly, full records of behaviour and performance were recorded.

Lambs used in the experiment.—The lambs were bred from the ewe flock as shown in Table 1. Lambing began on 2 March 1953 and continued until 15 April. Ninety lambs were born to the Half-bred ewes, and of these 72 were reared; 64 were born to the Clun ewes, and of these 56 were reared (Table 2). A full description of the management and lambing results will be given at the conclusion of the main experiment designed to compare the Half-bred and Clun ewes in respect of their merit for fat-lamb production. The routine of management and feeding followed was identical with that in the previous year, and all lambs were

TABLE 2. *Distribution in Numbers of Lambs Reared, According to Parentage and Sex*

	Half-bred			*Clun*			*All ewes*		
	Males	*Females*	*Total*	*Males*	*Females*	*Total*	*Males*	*Females*	*Total*
Ram A	16	19	35	14	15	29	30	34	64
Ram B	17	20	37	10	17	27	27	37	64
Total	33	39	72	24	32	56	57	71	128

managed similarly, the only differences being in the age when castrated and/or docked. Sale of the lambs commenced on 3 June 1953 and all but three were sold by 20 July 1953. These three lambs were the smallest lambs from sets of triplets and were sold on 10 August.

Each ram sired the same number of lambs reared, but there were fewer males than females, and the number of lambs out of the Clun ewes was disappointingly low.

Allocation of lambs to treatments.—In the design of the main experiment the ewes are grouped in blocks of four, each block consisting of two Half-breds and two Cluns, on the basis of similar live weights in autumn 1951. It was necessary to keep conditions within a block as similar as possible and accordingly all male lambs born to ewes in the same block were castrated at the same age. Similarly the female lambs born to ewes in the same block were docked at the same age. Allocation to treatments was therefore done at random on a block basis. An attempt was also made to secure information on simultaneous castrating and docking of ram lambs compared with castrating and docking at different ages. In the outcome the distribution of lambs to the various treatments was not entirely satisfactory. Some thought was given to the practicability of castrating members of a pair at the two different ages. If this were done, however, one member of a pair castrated soon after birth might well have received a setback and the difference in progress could not be ascribed solely to the difference in age of castration. Twins and triplets throughout the experiment were therefore castrated and docked at the same age.

Of the male lambs (Table 3) twenty were castrated within a week of birth and thirty-seven when between 21 and 30 days old. The essential comparison is accordingly based on these two groups. Twenty-seven were docked within a week of birth and thirty at the later age.

TABLE 3. *Distribution of Male Lambs According to Age at Castration and Docking*

	Half-bred			*Clun*			*All lambs*		
	Tailed 0–7 days	*Tailed 21–30 days*	*Total*	*Tailed 0–7 days*	*Tailed 21–30 days*	*Total*	*Tailed 0–7 days*	*Tailed 21–30 days*	*Total*
Castrated when 0–7 days old	2	10	12	4	4	8	6	14	20
Castrated when 21–30 days old	11	10	21	10	6	16	21	16	37
Total	13	20	33	14	10	24	27	30	57

Of the female lambs (Table 4) thirty-five were docked within a week of birth and thirty-six when between 21 and 30 days old. The effect of age at docking has been examined mainly in this sample, where there is no possible complication due to castration as in the case of the male lambs.

TABLE 4. *Distribution of Female Lambs According to Age at Docking*

	Half-bred	*Clun*	*All lambs*
Docked when 0–7 days old	18	17	35
Docked when 21–30 days old	21	15	36

Data recorded.—As in the previous experiment full data concerning the progress and performance of the lambs were recorded, viz. (*a*) date and time of birth; (*b*) weight at birth; (*c*) date and weight when castrated and/or docked; (*d*) weekly live weights from the beginning of May to date of sale; (*e*) date of sale and age when sold; (*f*) live weight when sold; (*g*) cold carcass weight. In the case of thirty-three female lambs, retained for breeding, no carcass data are available, and for the purposes of this experiment rate of live-weight gain has been calculated to the date on which each lamb first exceeded 80 lb. live weight.

In addition a careful record was made weekly of the condition of the lambs and the effect, where applicable, on scrotum, testicles, and tail, from the date of castration and/or docking. Also a ciné film was made showing the behaviour of the lambs following operation at different ages.

Methods used for castration and docking.—The same method of rubber-ring castration was used as in 1952 [1].

When docking lambs the tail was inserted through an expanded ring, the instrument slightly relaxed and the ring worked off the metal fingers with the free hand of the operator at the chosen site. The position was not selected according to an intervertebral articulation but at a distance

which would dock the lamb to the desired extent—i.e. about the level of the inferior commissure of the vulva.

The lambs were normally removed from their pen at the time of operation and placed in a separate pen until the batch had been dealt with. They were then reunited with the ewes. Occasionally it was necessary to leave one or two lambs in a special pen in order to carry out ciné recording at regular intervals.

Experimental Results

Physical effect of castration.—A general assessment of the physical effect of castration was obtained by direct observation of lambs dealt with under conditions of normal farm management. This was supplemented by ciné records and close and uninterrupted observations of several

TABLE 5. *Time Required for Scrotal Separation*

	No. of weeks after castration							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Lambs castrated when 0–7 days old . .	..	..	1	7	8	4	..	..
Lambs castrated when 21–30 days old .	..	1	1	6	14	9	5	1

individual lambs in pens for periods of several hours. Unfortunately it is not possible to estimate accurately the degree of discomfort or pain which is experienced by castrated lambs and the assessment of the effect of operating had to be based on interpretation of their behaviour.

With those lambs castrated within the first week of life little or no physical reaction was noted. On being released after the operation the lambs exhibited no symptoms which might be associated with the procedure and this absolute indifference persisted during the time the operation site was healing.

In contrast, the symptoms shown by lambs castrated when 21–30 days old appeared very soon after the operation. There was no effect immediately on applying the elastic ring unless it was allowed to snap off the expander; a gently released ring was well tolerated. The symptoms exhibited were similar to those described in 1952 [1], developing to a maximum during the first 15 minutes, often in the second 5-minute period after operation. Most lambs lay quietly in the second half-hour and all were resting in apparent contentment 1 hour after operation. There was considerable variation in the response of individual lambs, some being quite oblivious of the interference. The following day these lambs may not have been quite as lively as usual but there was not the stiffness seen after Burdizzo castration.

The weekly clinical inspections following the operation were designed to record the respective times of scrotal separation and of complete healing.

Table 5 shows the numbers of lambs in which scrotal separation was complete for each week following the operation. All the scrota had been

shed by the time of the eighth weekly inspection, but there was a tendency for the scrotum to remain attached for about a week longer with lambs castrated at the older age.

TABLE 6. *Time Required for Complete Healing*

	No. of weeks after castration									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Lambs castrated when 0–7 days old	..	..	..	..	10	4	6	..	..	..
Lambs castrated when 21–30 days old	..	..	..	..	1	12	16	7	..	1

The criterion for complete healing was the establishment of skin continuity with no obvious scab. Lambs castrated at the later age tended to heal in a slightly longer time than those castrated in the first week, and thus healing was complete approximately a week after the shedding of the scrotum.

A difference between the two age-groups was noted in the incidence of pus in the open wound which developed on the proximal side of the rubber band.

TABLE 7. *Occurrence of Pus*

	No. of occasions when pus was noted			
	1	*2*	*3*	*4*
Lambs castrated when 0–7 days old	6	..	..	..
Lambs castrated when 21–30 days old	6	9	8	6

Of the lambs castrated within 1 week from birth 6, or 30 per cent., showed a wound with greenish pus, whereas in the later castrated group 29 or 78 per cent. showed pus. In 1952 70 per cent. of lambs castrated at 16–39 days old similarly showed pus and the much lower figure in 1953 for the early castrated group suggests that as far as a dirty wound is of importance it is better to castrate soon after birth. It was noted both in 1952 [1] and in 1953 that the greenish pus overlay a healthy layer of granulation tissue, and the entry of infection into such a wound may not be likely but cannot be disregarded. The pyogenic nature of the wound may prove favourable for blowfly 'strike' to occur in suitable conditions though, in fact, no strike was experienced in the lambs concerned in this experiment.

Physical effect of docking.—Docking the lambs with rubber-ring ligatures proved effective at both ages, but the discomfort produced was generally much more noticeable in the older age-group studied. There was no apparent discomfort or pain in lambs docked before they were 48 hours old. With increasing age, however, the intensity of symptoms became more marked. Docking at 4 days old sometimes produced a

degree of uneasiness, indicated by frequent getting up and down which lasted 10–15 minutes.

At 3–4 weeks docking was followed by much more severe symptoms associated with contortions of the body, repeated heavy falling to the ground and wild kicking, bucking, and rolling. Symptoms were generally seen as soon as the lamb was released and developed to a maximum in the first few minutes after the operation. Some lambs were seen to lick the tail once or twice but there was no serious effort to interfere with the ring with the mouth. There was no excessive bleating. The typical manifestation continued for about 30 minutes and uneasiness was present for a full hour. During the second half-hour after docking, however, it was usual for the periods of quiet lying to become longer and in the second hour after operation the lambs were all found to suckle, graze, and sleep in apparent contentment. There was considerable variation in individual response and occasionally after some slight initial discomfort a lamb settled down 5 or 10 minutes after the operation. In other lambs where staggering, rolling, and contortions predominated it was probably only after 30 or 60 minutes that the quiet and apparently contented state was reached.

No swelling of the tail below the ring was found; the arrest of circulation caused the tail to become cold and necrotic and the atrophy was progressive. In one or two cases the necrotic, shrunken tail became green or black and very occasionally a moist, malodorous stage developed for a short period. Attempts to determine loss of sensation by pricking the tail were not very successful but the cessation of symptoms probably corresponded with the development of anaesthesia. This lack of sensation may, in a few lambs, have been responsible for a break in the bony structure of the tail about 1 in. below the ring. Probably the limp, senseless tail was trodden upon and this resulted in a jerk as the lamb pulled away. This lesion was of no detriment for although the tail may have parted first at this site, leaving a stump behind, the final slough took place proximal to the ring. In a very few cases such an accident was responsible for slight haemorrhage from the region of eventual separation. The tail nearly always divided at the intercoccygeal articulation immediately proximal to the ring which invariably accompanied the shrivelled remnant. Sometimes although the tail had divided this remnant was attached by wool caught in the ring and the wound was healing normally under a dry, healthy crust. It was unusual for coccygeal bone to be exposed, but if this happened the protruding bone was sloughed or healed over by scab and later skin.

In both groups of lambs tail shedding occurred in the 3rd and 4th weeks after operation, with a tendency to earlier shedding in the early docked group. There was a slight tendency for the tails of female lambs to be shed rather less than a week earlier than those of male lambs.

The time taken for complete healing, that is, the establishment of skin continuity with no obvious scab, was from 5 to 6 weeks for most lambs docked within a week of birth and from 5 to 7 weeks for those lambs docked at 3–4 weeks old.

In a small number of cases the wound of separation showed the

presence of pus of a light-green colour which was not malodorous and overlay healthy granulation tissue. Five cases occurred in the early docked group and nine in the later docked group. This represents a proportion of 11 per cent. compared with 12 per cent. found in 1952 when the lambs were docked at ages of from 16 to 39 days. In one case pus persisted for more than 2 weeks, in three cases for more than 1 week and less than 2, and in the remainder it persisted for less than 1 week. There was no fly strike, and similar considerations regarding wound infection apply as with castration.

Presentation of results of performance.—A direct result of the method used in allocating lambs to the respective treatments was the discrepancy in numbers both in respect of parentage and times of operation. For example, twelve lambs only out of the Half-bred ewes were castrated within a week of birth, whereas twenty-one were castrated at the later age. In examining the results therefore it is important to take note of the numbers of singles, twins, and triplets comprised in each sample. In all, fourteen sets of triplets were born and a high proportion of these were reared by their own dams. From an experimental point of view this performance was, however, no asset.

The results for castration and docking are presented in Tables 8–10, and are discussed under separate headings.

Performance of Male Lambs Castrated at Different Ages

Age and live weight at time of castration.—On average the live weight of lambs castrated at the earlier age was 15 lb. and that of the lambs castrated about 21 days later was 30½ lb. At birth there was no difference in live weight between the two groups of lambs out of the Half-bred ewes, but with those out of Clun ewes, the earlier castrated lambs weighed 2 lb. heavier. This difference was mainly due to the inclusion of five triplets in the later castrated group.

Sale weight.—The live weights at which the lambs in the various groups were sold varied more than had been anticipated. This was particularly noticeable in lambs out of the Clun ewes, even in the case of twins. The variation was due to differences in the incidence of lambing of ewes in the various groups, coupled with the fact that on Whit Monday and August Bank Holiday Monday no markets were held, and lambs due for sale on those 2 days had to be held back for a further week. The two groups of twins out of Half-bred ewes were, however, sold at the same average weight.

Dressing percentage.—The dressing percentage was calculated by expressing the cold carcass weight as recorded in the Leeds Corporation Abattoir as a percentage of the live weight of the lambs (unfasted) on the morning of the day of sale. Lambs castrated at the early age produced carcasses which were 3·2 lb. heavier than those castrated later. This difference was reflected in the dressing percentage, which was 49·1 per cent. compared with 46·4 per cent., an increase of 2·7. A comparison of the results from twin lambs only reveals a similar margin. Twins castrated

TABLE 8. *Results: Castration of Male Lambs*

Lambs out of Half-bred ewes

Age when castrated	*Total no. of lambs*	*No. of lambs born and reared as*			*Other lambs*	*Weight at birth (lb.)*	*Age when castrated (days)*	*Weight when castrated (lb.)*	*Weight when sold (lb.)*	*Carcass weight (lb.)*	*Dressing percentage*	*Age when sold (days)*	*Gain in live weight (lb.)*	*Live-weight gain per day (lb.)*
		Singles	*Twins*	*Triplets*										
0–7 days	12	1	7	..	4	12·2	4	15·4	84·3	41·1	48·6	88·5	72·1	0·83
21–30 days	21	1	12	7	1	12·0	25	32·1	83·6	39·1	46·7	88·7	71·6	0·82

Lambs out of Clun ewes

0–7 days	8	3	5	..	..	12·0	4	14·7	85·8	42·6	49·7	83·9	73·8	0·89
21–30 days	16	1	8	5	2	10·4	25	28·6	81·9	37·7	45·9	99·1	71·5	0·74

All lambs

0–7 days	20	4	12	..	4	12·1	4	15·1	84·9	41·7	49·1	86·7	72·8	0·85
21–30 days	37	2	20	12	3	11·3	25	30·6	82·9	38·5	46·4	93·2	71·6	0·78

within a week of birth dressed out at 48·3 per cent. compared with 46·6 per cent. given by those castrated between 21 and 30 days.

Age sold.—Although on average the group of lambs castrated within a week of birth required a week less to attain sale weight than the group castrated at the later age, this difference was caused mainly by the slower progress of the high proportion of triplets born to the Clun ewes, and also by the greater live weight to which the lambs were carried (see under Sale weight on p. 195). Twin lambs in the two groups were, however, sold at the same age, 87 and 88 days respectively.

Daily live-weight gain.—This was calculated by dividing the gain in weight of the lambs from birth to date of sale by the age in days when sold.

The difference in daily live-weight gain between the two groups is again an expression of the slower progress of the triplets out of Clun ewes. Difference in the progress of twin lambs was small, early castrated twins gaining weight at the rate of 0·84 lb. per day, compared with 0·81 lb. per day gained by the later castrated twins.

Performance of Female Lambs Docked at Different Ages

Age and live weight at time of docking.—On average the difference in age at time of docking between the two groups was just over 3 weeks, and the second group were rather more than twice as heavy in weight as the first group.

The lambs in the two docking groups had equal birth weights on average, but there was some variation in respect of lambs born to the two different breeds of ewe. This again was due to the distribution of triplets. With twins, however, the differences were not marked, early docked twins out of Half-bred ewes weighing 12·0 lb. against 11·2 lb. for the late docked twins, and those out of Clun ewes weighing 10·1 lb. against 10·5 lb.

Sale weight.—On average all groups of female lambs were sold at the same live weight of 83–4 lb., the degree of variation noted in connexion with the male lambs being absent.

Dressing percentage.—As already pointed out thirty-three ewe lambs were retained for breeding, and thus carcass records were obtained only for thirty-eight which were actually sold. On average no difference in dressing percentage was found, and the small numbers available, when subdivision is made into singles, twins, and triplets, do not afford a sound basis for further comment in respect of the twins. It is worthy of note, however, that the average for all the female lambs sold (47·2 per cent.) was above that for male lambs castrated at the later age of 21–30 days (46·4 per cent.), but below that for male lambs castrated within a week of birth (49·1 per cent.).

Age sold.—Although on average there was very little difference between the two groups in respect of age when sold (or transferred to breeding flock), there were quite big differences in the Half-bred and Clun lambs considered separately. As with birth weights, these differences were probably due to the proportion of triplets. With twins there

TABLE 9. *Results: Docking of Female Lambs*

Lambs out of Half-bred ewes

Age when docked	*Total no. of lambs*	*No. of lambs born and reared as*			*Other lambs*	*Weight at birth (lb.)*	*Age when docked (days)*	*Weight when docked (lb.)*	*Weight when sold (lb.)*	*Carcass* weight (lb.)*	*Dressing* percentage*	*Age when sold (days)*	*Gain in live weight (lb.)*	*Live-weight gain per day (lb.)*
		Singles	*Twins*	*Triplets*										
0–7 days .	18	2	8	2	6	11·7	3	14·0	84·1	40·8	47·3	87·1	72·4	0·84
21–30 days .	21	1	9	6	5	10·5	26½	30·6	83·0	38·9	47·4	97·0	72·5	0·76

* 0–7 days, 9 lambs; 21–30 days, 14 lambs.

Lambs out of Clun ewes

0–7 days .	17	..	9	4	4	9·4	4	11·7	82·6	38·9	47·4	102·6	73·2	0·72
21–30 days .	15	1	14	..	..	10·9	26	30·5	82·4	38·5	46·7	94·5	71·5	0·77

* 0–7 days, 9 lambs; 21–30 days, 6 lambs.

All lambs

0–7 days .	35	2	17	6	10	10·6	3½	12·9	83·4	39·8	47·4	94·6	72·8	0·78
21–30 days .	36	2	23	6	5	10·7	26	30·6	82·8	38·7	47·2	95·9	72·1	0·76

* 0–7 days, 18 lambs; 21–30 days, 20 lambs.

was no difference between the two groups of Clun lambs, and about 6 days between the two groups of Half-bred lambs.

Daily live-weight gain.—Similar remarks apply here. Between the twin lambs of the docked group born to the Half-bred and Clun ewes respectively there was little difference in rate of live-weight gain per day.

Performance of Male Lambs Docked at Different Ages

Table 10 gives the results from male lambs arranged to show the effect of docking at the two different ages, with reference to the age of castration. There are four groups: (1) lambs castrated and docked within a week of birth; (2) lambs castrated within a week of birth and docked when 21–30 days old; (3) lambs castrated and docked when 21–30 days old; (4) lambs castrated when 21–30 days old and docked within a week of birth.

TABLE 10. *Data from Male Lambs to Show Effect of Docking at Two Ages*

	Age when castrated	*No. of lambs*	*Weight at birth (lb.)*	*Live weight when sold (lb.)*	*Carcass weight (lb.)*	*Dressing percentage*	*Age when sold (days)*	*Live-weight gain per day (lb.)*
Docked 0–7 days	0–7 days	6	11·9	85·5	43·6	51·0	81·3	0·92
	21–30 days	21	11·3	82·3	38·1	46·3	92·0	0·79
		27	11·4	83·0	39·3	47·3	89·6	0·82
Docked 21–30 days	0–7 days	14	12·2	84·6	40·9	48·2	88·9	0·82
	21–30 days	16	11·3	83·6	39·0	46·6	94·8	0·78
		30	11·7	84·1	39·9	47·4	92·1	0·80

When these groups are further subdivided into breed categories it will be realized that the numbers in each sub-group are small and thus the proportion of singles, twins, and triplets seriously affects the average figures. It is not proposed, therefore, to examine each item recorded in detail.

The results for all the lambs do not in fact reveal any appreciable difference in performance due to docking at different ages. There was no difference in dressing percentage, nor in rate of live-weight gain; the average sale weight was 83·0 lb. in the early docked group and 84·1 lb. in the later docked group; and the later docked group were only 2½ days older at the date of sale.

Discussion of Results

Castration.—The results show that castration by the rubber-ring ligature can be carried out either soon after birth or when the lambs are between 3 and 4 weeks old with little difference in their subsequent performance. Although emphasis has been laid in this report on the necessity for studying the performance of singles, twins, and triplets separately, in practice it is the average performance of all the lambs which

is of consequence, and on average, the performance figures of the two groups were very similar. There was a possible exception in the case of dressing percentage, where castration at the earlier age may have been of real advantage in that slightly heavier carcasses were produced for a given live weight, indicative of slightly fatter lambs at the time of sale.

Point is added to this by comparing the results for male lambs castrated when 3–4 weeks old in this experiment with those obtained for lambs castrated by the same method at a similar age in 1952 (Table 11).

TABLE 11. *Results from Lambs Castrated at 3–5 Weeks by the Rubber-ring Ligature Method in 1952 and 1953*

	No. of lambs	*Birth weight (lb.)*	*Average age at castration (days)*	*Weight when sold (lb.)*	*Carcass weight (lb.)*	*Dressing percentage*	*Age when sold (days)*	*Liveweight gain per day (lb.)*
1952	34	10·3	30	82½	37¾	45¾	99½	0·74
1953	37	11·3	25	83	38½	46½	93	0·78

The figures are quite comparable but show that in 1953 the lambs made slightly better progress, benefiting probably by the heavier weight at birth. Even so the lambs castrated soon after birth gave a dressing percentage greater by nearly 3 per cent. and a carcass weight greater by 3 lb.

From the physical aspect there would seem to be real benefit by castrating at the earlier rather than the later age. Lambs castrated early were not affected at all by the operation, or at the most to a very slight extent. This indifference was replaced in older lambs by symptoms that increased in intensity with the age at which the operation was performed. The point of maximum severity of the symptoms may well be between the ages of 3 and 5 weeks but information on the older lambs was not sufficient to be certain. There was no suggestion that more severe symptoms are to be found in the later part of the age range for which symptoms have been recorded.

In practice there is also merit in castrating soon after birth in that the lambs can be turned away with the ewes, and no further gathering is needed for the specific operation of castration. It should be emphasized, however, that the lambs used in this experiment were born in March and April. Without further investigation it would be unwise to prophesy similar results when lambing occurs much earlier in the year or during unfavourable conditions. Further, the advantage gained in carcass yield, though of significance in fat lamb production, might not be so apparent in lambs produced for fattening at much later ages.

Docking.—As in castration the docking of female lambs by use of rubber-ring ligatures can be carried out soon after birth or at 3–4 weeks old without causing any difference in performance. It is quite clear, however, that the operation causes symptoms of more acute discomfort

or pain than those caused by castration alone. Such symptoms appeared when docking was carried out after 48 hours of age, in contrast to castrated lambs which were apparently unaffected when operated on during their first week of life. This was found to be so in both 1952 and 1953. The maximum severity of symptoms after docking may well lie between the ages of 3 and 5 weeks but there was little to suggest that the older lambs in this age-group were more severely affected than the younger ones. Although the rubber-ring method is easy, quick, clean, cheap, and convenient to use, the post-operational symptoms seen in the older lambs are its main disadvantage. These symptoms may well be less painful and more transient than those produced by traditional methods of docking, and they can, of course, be avoided altogether if lambs are operated upon when less than 48 hours old.

Docking and castrating simultaneously.—It might be expected that the double shock of castrating and docking male lambs simultaneously would cause more pain and also affect subsequent performance. It is unfortunate that in the experiment the number of lambs available for this particular study was so small and varied in composition. The results from the female lambs, however, indicated that no difference in performance due to difference in age at docking need be expected, and on a flock basis this is supported by the results from the male lambs. In other words, the docking of lambs soon after birth or when 3–5 weeks old made no difference to their performance subsequent to castration at the early or late ages. Similarly the double operation of castration and docking caused no more symptoms than those resulting from each operation carried out at separate times.

The practical conclusion from the results and studies presented in this paper is that with male lambs castration with the rubber-ring ligature can be carried out satisfactorily within a week of birth, and that when this method is used all lambs would best be docked within 48 hours of birth.

Summary

A study of the use of the rubber-ring ligature as a method of castrating and docking lambs has been carried out on the Leeds University Farm with particular reference to two times of operation, viz. within a week of birth and at 21–30 days old, the lambs subsequently being sold at live weights of approximately 80 lb.

Of a total of 128 lambs, out of Half-bred and Clun ewes, sired by Suffolk Rams, 62 were docked before they were a week old and 66 at 21–30 days old.

Of 57 male lambs, 20 were castrated at the early age and 37 at the later age. The physical effects of both operations were recorded and clinical observations made at weekly intervals. The performance of the lambs was measured by weighing regularly and recording live and dead weights and age when sold.

After castration the early age-group killed out at a higher dressing percentage than the later age-group, but in other respects there was no difference in performance on average. Symptoms of discomfort were

exhibited by the later castrated lambs, but none by the early castrated lambs. The average time required for scrotal separation was 4–6 weeks in the early castrated group and slightly longer in the later castrated group. Similarly the average time required for healing was 5–7 weeks in the first group and 6–8 weeks in the second. Although pus developed in the wound in some cases and represented a possible source of entry of infection, no infection in fact occurred nor was there any 'strike' by blowfly.

After docking there was no difference in performance between the two age-groups, but discomfort was experienced to a greater or less degree by all lambs with the exception of those docked within 48 hours of birth. The average time for severance of the tail was 3–4 weeks and complete healing took place after 5–7 weeks. A few cases of pus development occurred, but there was no infection and no blowfly 'strike'.

The rubber-ring method offers a simple, easy, and practical method of both castrating and docking within 2 days of birth, but the possibility of infection cannot be entirely disregarded under conditions favourable for disease incidence.

Acknowledgements.—The authors record their appreciation of the work carried out by Mr. J. B. Swales and Mr. D. R. Hodgson, who were responsible for much of the detailed weighing and recording of the progress of the lambs on the University Farm, and they also thank Mr. D. L. Wynn, Area Slaughterhouse Agent, Ministry of Food, together with the authorities of the Leeds Corporation Abattoir, for their co-operation in enabling records of carcass weights to be obtained.

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(*Received 10 March 1954; as revised, 22 July 1954*)

MANURING HEVEA V: SOME LONG-TERM EFFECTS IN THE DUNLOP (MALAYA) EXPERIMENTS

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EXTENSIVE manuring experiments were started on the Dunlop rubber estates between 1930 and 1934. Earlier papers in this series [1, 2, 3, and 4] showed the progress of the first 9 or 10 years, up to the time when the Japanese occupation caused work to be suspended. It is the purpose of the present paper to report on such post-occupation measurements as are available. Old plots were easily identifiable, and although treatments were not renewed it was considered advisable to undertake further measurements, since there is a scarcity of information about the duration of the residual effects of manuring when treatment has ceased. Response to treatment may be slow and is partly put to reserve in the improved bark of the trees, so that the economic assessment of returns is incomplete without such long-term information.

Edge effects.—An essential preliminary after the lapse of so many years was to examine the question of the spread of treatment effects beyond the plot boundaries. Individual tree roots extend far beyond the spread of the branches in the search for nutrients, and also there is present in *Hevea* the possibility of nutrient sharing through root grafting. Measured effects will be discounted if untreated trees are able to steal nutrients applied to an adjacent plot. This possibility, often described as poaching, was taken account of in the experimental layouts. It is not practicable to separate a large number of plots by perfectly safe distances, but as a compromise one or more rows of trees were left as guards. If these prove insufficient then it is the control plots which will call for special attention, because, on the law of diminishing returns, the unintended transfer of a fractional amount of a treatment will have less effect as a loss from a treated plot than it will have as a gain to an untreated one.

Poaching was already evident in 1940, when Haines [5] reported measurements of girth and foliage density near plot boundaries, made on an experiment on mature trees where annual applications had gone on for 10 years. Here a single guard row of trees had been left, but the benefit of the manures was plainly traceable up to the third row within the control plot, representing a travel of at least 80 ft. from the area of treatment. Routine girth records had been kept without regard to this source of error. When correction was made by discarding the affected rows of trees it was found that the effect of manuring on girth, which had been assessed at 8·9 cm. using all original trees, was 21·1 cm. when using those without poaching bias. Of this correction, about one-third was contributed by a raising of the figure for girth of manured trees and the remaining two-thirds by a lowering of the unmanured figure. It was reckoned that the square plots of 200 trees originally laid down had only

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about forty left at the core of the control plots which could be considered as unaffected by poaching. Tests on other experiments showed that such developments were less extensive in more backward trees.

The most important group of experiments to be considered had the 27-plot factorial design (testing the three nutrients N, P, and K each at three levels 0, 1, 2) with long plots of three rows of trees, experimental and guard plots alternating. Each outside row of a guard plot received the same treatment as its neighbouring experimental plot, so that travelling across the field one would find five rows of like treatment separated by single untreated rows. Started in 1934, these experiments received eight annual applications of manures ending in 1941. One such experiment was examined for poaching developments in 1948. The trees had been so small at the start (budded 1932) that roots probably did not penetrate the guards for a year or two. Response to phosphorus was very vigorous during the whole immature phase, and evidence of poaching of this element was therefore sought in the 1948 test. Two sites were picked out where the random layout had provided an experimental plot with no phosphorus lying between two others each having double phosphorus. The other treatments were known to have but small effects and they could be neglected in this test. Traverses for girth measurement were so arranged across the experimental and guard plots that Row 1 was the middle row of one double-phosphorus plot. Then Rows 2 and 3 had the same treatment (Row 2 in its own right and Row 3 as guard); Rows 4 to 10 had no phosphorus (4, 5, 9, and 10 belonging to guard plots and 6, 7, 8 forming the experimental plot with no phosphorus); and Rows 11, 12, and 13 were symmetrical with Rows 3, 2, and 1. Fig. 1 depicts the average girths, combining some twenty traverses on each of two sites, with this arrangement of rows. The so-called 'ideal' curve for no poaching is drawn from the three values of the experimental plots in the regular measurements, where a much larger sample taken from all three rows of trees was used.

There was some slight evidence of lost effect in the outside row of manured trees, while the next row to it, the first row without phosphorus treatment, showed about 80 per cent. of the phosphorus effect. In the next row this was reduced, but was still over 35 per cent. These are the rows originally assigned as guards, and the need for such provision has been very clearly proved for these later years. It appears probable that Rows 6 and 8 in the experimental plot have not been quite free from poaching, so that further measurements on these experiments have been restricted to the middle rows. Instead of sampling one tree in five on three rows, which was the previous routine, all the trees in the middle row are taken.

Growth.—Regular growth records were kept up to the Japanese occupation, but unfortunately many details were lost and the last full set now available comprises those for 1938 (after five annual dressings of fertilizers). The trees had then reached a girth of 45 cm., a little short of the 50 cm. standard which is reckoned mature enough for tapping to start. The interval of 10 years until the new records in 1948 was covered by three more annual dressings over a period in which tapping was

started (according to the development in each field) and then 4 or 5 years' rest with finally a gradual resumption of tapping. The average growth in these 10 years was a little under 30 cm., showing how very much the girthing rate falls off on lower-grade sites when trees become mature. An average girthing of 3 cm. per year is little over the inch standard that was reckoned in earlier work to be a minimum in old seedling rubber for maintaining a stable yield.

Table 1 shows the main effects and interactions for seven experiments on the same estate, similar in age and history, No. 1 being the experiment

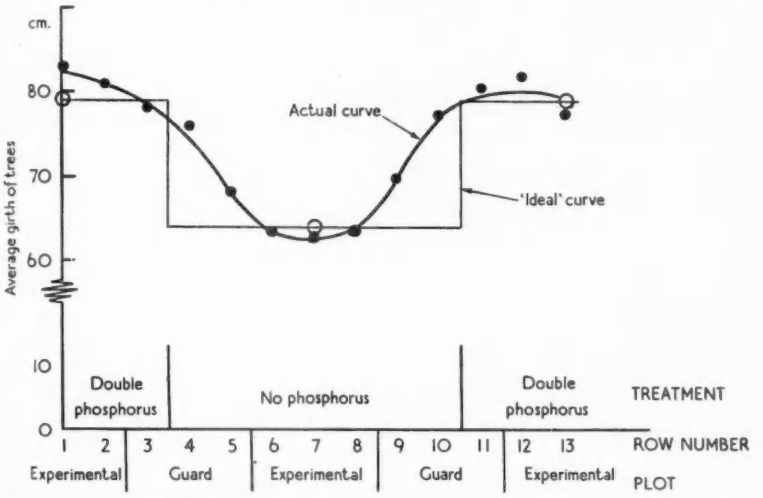

FIG. 1. The poaching of a phosphorus treatment, shown by the girths of contiguous rows of trees

selected for the poaching test already described. The early effects on growth have on the whole been maintained. The phosphorus effect, which was very marked in all cases, increased significantly during the last 10 years in four experiments out of seven. Of the other three, two had the Clone B.D. 5 which was very backward on this estate, and the remaining one (No. 10) suffered serious storm damage in 1936. It is to be noted that the size of plots was reduced in 1939 for reasons of economy, so that the 1948 figures as compared with those of 1938 refer to a reduced area of land as well as to a reduced number of trees.

Two other experiments of the same series but on older buddings were available, their results being recorded in Table 2. The trees were mature at the time of the first manuring (1934) and the results bring out the greater importance of nitrogen for older trees. The 10 or 11 years' growth was slightly less than in the younger series. Nitrogen had about equal importance to phosphorus in No. 6 and greater importance in No. 7. The positive interaction between nitrogen and phosphorus in No. 7 was also large enough to attract attention. The phosphorus effect

TABLE 1. *Girth Effects before and after Japanese Occupation, Younger Series*
(Mean girths and responses in cm.)

No. of Expt. Year	Clone	Mean	Main effects							Interactions			
			N_1	N_2	P_1	P_2	K_1	K_2	S.E. ±	N_2P_2	N_2K_2	P_2K_2	S.E. ±
1. 1938	G. 1	45·5	+1·3†	+2·5†	+ 8·3†	+11·0†	+0·8	+1·1	0·43	+0·9	−0·5	−0·6	0·54
1948		72·8	+2·5*	+2·3*	+11·6†	+14·8†	−1·0	−2·1	1·05	+0·2	+0·2	−0·5	1·28
Difference		27·3	+1·2	−0·2	+3·3*	+3·8*	−1·8	−3·2*	1·35	−0·7	+0·7	+0·1	1·65
2. 1938	B.D. 5	42·9	+1·1	+1·6*	+5·2†	+7·2†	−0·3	−0·1	0·54	+1·7*	−1·5*	−0·5	0·66
1948		70·6	+0·9	+3·0*	+7·7†	+10·0†	−1·0	0	0·86	+0·2	−1·9	+0·2	1·05
Difference		27·7	−0·2	+1·4	+2·5*	+2·8*	−0·7	+0·1	1·12	−1·5	−0·4	+0·7	1·37
3. 1938	B.D. 5	44·0	+2·9	+4·6†	+5·8†	+8·0†	−1·2	−0·8	1·11	+0·7	+2·4	+1·2	1·37
1948		66·5	+1·1	+1·9	+5·6†	+6·4†	−0·2	+0·9	1·24	+0·6	+3·3*	−0·7	1·52
Difference		22·5	−1·8	−2·7	−0·2	−1·6	+1·0	+1·7	1·48	+0·1	+0·9	−1·9	1·81
5. 1938	Tj. 1	47·2	+0·9	+1·9*	+5·9†	+6·8†	−0·7	−1·5	0·83	+0·2	+0·5	+0·1	1·02
1948		78·5	+0·2	+1·8	+7·6†	+9·6†	−0·1	+0·1	1·08	+0·9	+1·4	−2·7*	1·33
Difference		31·3	−0·7	−0·1	+1·7	+2·8†	+0·6	+1·6	0·89	+0·7	+0·9	−2·8*	1·09
8. 1938	B.D. 5	41·9	+1·0	+2·0†	+4·9†	+7·4†	+1·4*	+1·1	0·61	+0·7	+0·6	+0·5	0·75
1949		71·8	+1·7	+2·6†	+5·2†	+6·5†	+0·6	+1·5*	0·72	+0·3	−0·5	+0·1	0·88
Difference		29·9	+0·7	+0·6	+0·3	−0·9	−0·8	+0·4	0·69	−0·4	−1·1	−0·4	0·84
9. 1938	P.B. 186	45·5	+2·2*	+1·8*	+6·6†	+8·8†	+0·5	−0·1	0·62	−0·8	−0·8	+0·5	0·75
1948		75·9	+1·9	+2·4*	+10·2†	+12·6†	+1·6	+1·2	0·96	+1·0	+1·1	+1·2	1·17
Difference		30·4	−0·3	+0·6	+3·6†	+3·8†	+1·1	+1·3	0·82	+1·8	+1·9	+0·7	1·01
10. 1938	P.B. 23	48·5	+2·0	+2·1	+4·5†	+6·6†	+0·5	+2·5*	1·16	−0·3	−3·0*	−0·4	1·42
1948		76·4	+1·7	+0·1	+4·9†	+6·4†	−0·2	+2·9*	1·29	+0·9	−1·4	−1·9	1·58
Difference		27·9	−0·3	−2·0	+0·4	−0·2	−0·7	+0·4	1·71	+1·2	+1·6	−1·5	2·09

* Sig. at P = 0·05. † Sig. at P = 0·01.
1938 Represents cumulative effects of five annual applications of fertilizers.
1948 Effects as further developed by 3 years' manuring followed by 7 years' no-manure.

TABLE 2. *Girth Effects before and after Japanese Occupation, Older Series*
(Mean girths and responses in cm.)

No. of Expt. Year	*Clone*	*Mean*	*Main effects*							*Interactions*			
			N_1	N_2	P_1	P_2	K_1	K_2	*S.E.* ±	N_2P_2	N_2K_2	P_2K_2	*S.E.* ±
7. 1937	Av. 49	55·4	2·1†	1·7*	2·9†	2·6†	−0·4	0·9	0·69	−0·5	+0·6	0	0·84
1948		79·0	10·2†	9·5†	7·1*	7·3†	−1·6	−1·5	2·4	5·5	0·3	2·1	2·9
Difference		23·6	8·1†	7·8†	4·2	4·7*	−1·2	−2·4	2·2	6·0*	−0·3	+2·1	2·7
6. 1937	Av. 50	59·3	−0·4	2·2	2·2	3·0*	2·2	−0·4	1·3	2·1	−1·4	−1·3	1·5
1948		80·2	5·1	9·4*	9·6*	8·7*	−0·5	−2·0	3·4	0·8	1·3	−0·6	4·1
Difference		20·9	+5·5	7·2*	7·4*	5·7*	−2·7	−1·6	2·8	−1·3	+2·7	+0·7	3·5

* Sig. at P = 0·05. † Sig. at P = 0·01.

TABLE 3. *Yield of Rubber Determined by Rounds of Sampling*
(Oz. of dry rubber/tree/tapping)

No. of Expt.	*Clone*		*Mean yield*	*Main effects*							*Interactions*			
				N_1	N_2	P_1	P_2	K_1	K_2	*S.E.* ±	N_2P_2	N_2K_2	P_2K_2	*S.E.* ±
1	G. 1	3 rounds 1949	2·04	0·11	0·01	0·39†	0·57†	−0·15	−0·16	0·074	−0·12	−0·23*	−0·05	0·091
		2 rounds 1953	1·22	0·02	0·06	0·24*	0·40†	−0·09	−0·05	0·100	+0·09	+0·01	−0·04	0·122
7	Av. 49	3 rounds 1949	1·72	0·30†	0·17	0·05	0·09	−0·08	−0·12	0·086	+0·22*	−0·01	−0·10	0·105

* Sig. at P = 0·05. † Sig. at P = 0·01.

was very much slower to develop in the older trees, but in the course of time it built up to similar values. The resting during the occupation must have permitted better general growth than under tapping. The practical equivalence of the responses to single and to double dressings may indicate that annual dressings are too frequent for economy, but in so far as the later effects are residuals it might be expected that the double dressing would have been superior and the result is anomalous.

Yield.—Yield records were obtained by rounds of cup-coagulation on a sample of trees, covering a block of nine plots on a single tapping day. Such records since the occupation have been meagre, but the two experiments entered in Table 3 for rounds of sampling at three different periods serve to reinforce the conclusions from the growth figures. No. 1 experiment gave a phosphorus effect in yield which was proportionately much larger than the effect on growth. The percentage phosphorus effects on the three separate rounds in 1949 were 34·3, 16·6, and 33·9 per

TABLE 4. *Growth Effects during 8 Months*

(Expt. No. 8, Clone B.D. 5. Average growth, 3·60 cm. girth. Effects in cm.)

	P_0	P_1	P_2	*Mean*
S (cover stripped) . . .	0·877	0·605	0·354	0·612
M (cover manured with P) . .	0·784	0·231	−0·010	0·335

S.E. within table, ±0·166.

cent., the low figure corresponding to a period of dry weather. The 1953 figures show that this effect has been well maintained. The structural growth benefits secured by the early manuring were thus giving a return of nearly one-third of the crop many years after the treatments had ceased. Since the phosphorus treatment had already paid for itself many times over by advancing the date of maturity and was now doing so again by a most durable increase in crop, this experiment affords a very clear example of high economic return.

No. 7 experiment confirmed, in the nitrogen effect, that a yield benefit can be reaped long after treatments have stopped. The N × P interaction that was noted for growth appeared also in these yields.

One further point of interest concerns No. 8 experiment in which the plots were split into quarters at a time when the trees were approaching maturity and the original cover of *Centrosema* was very sparse and faded. The new treatments under test were, (1) to compare cover with clean weeding; (2) to manure the cover with phosphate with a view to its restoration. Although this project was early interrupted, the first indications gave very clear evidence on two points, namely, that stripping a cover gives an immediate benefit to the trees (presumably by the removal of competition), and that manuring with a fertilizer which is a common need of both cover and tree stimulates them both even though the method of application favours the cover and increases the competition. Table 4 shows the effects of the treatments S (stripping cover) and M (manuring cover with rock phosphate), applied to the main phosphate treatments built up since the start of the experiment.

Since the responses to small amounts of phosphate have been phenomenal it is interesting to note that stripping the cover has temporarily had an even larger effect than manuring with phosphate. It probably would not prove as lasting. The intention had been to follow up the long-term changes under cover and under clean weeding and by measurement to pass judgement on the general belief that cover is advantageous. It was to be expected that treatment M would have little effect on phosphate plots and would exert its main influence on those so far

TABLE 5. *Girth Measurements, 25-plot Experiments in Old Rubber*
(*Girth in cm., 1948*)

No. of Expt.	*Control*	N	NK	NPK *with organic*	NPK *inorganic*	*S.E.* ±
1	108·1	126·3	124·1	131·8	128·8	3·4
3	110·9	130·5	125·5	135·9	134·3	2·6
6	95·2	100·9	103·8	119·7	109·6	2·7
9	88·0	98·6	95·8	105·8	108·8	3·3
8	113·5	126·5	115·5	133·5	131·2	3·5
10	83·6	102·5	102·6	110·4	109·9	2·3
11	82·2	100·8	113·2	110·1	108·9	4·5
Average 7 expts.	97·4	112·3	111·5	121·0	118·8	..
Average effects 1948	..	14·9	14·1	23·6	21·4	1·74
,, ,, 1937	..	7·2	7·3	8·3	7·5	..

starved of phosphate. It is not so clear why there is the same tendency with the treatment S. There was a more bulky cover on the phosphate plots (conserved by the P stolen from the tree-treatments) which might have been expected to enhance the effect of stripping, but the result shows clearly that the most backward plots have taken the most benefit. It is, of course, in such plots that competition would be most serious although diminished by the failing strength of the cover, but it is interesting that such a positive effect follows a mere removal of competition.

Old 25-plot experiments.—Various reports have been made on this early series of experiments, started in 1931 on mature seedling trees [1–4, 6]. The plots had long since given the chief answers to the questions for which they were designed and by 1948 many of the sites had become very senile and ragged. Great structural differences due to earlier treatment were often to be seen between plots now equally denuded of leaves. Although it did not seem feasible to revive serious interest in these experiments it was thought worth while to take a series of girth measurements. The general history of growth follows, based on averages of seven remaining experiments.

Beginning in 1931 with a girth of 68 cm. (which represented an average annual growth from planting of just over 5 cm.), during the first 6 years of the experiments with annual manuring, namely, 1931–7, the unmanured plots grew only 1·2 cm. per annum while the manured plots made 3·0 cm. per annum. The further period of 11 years began with

three annual manurings and ended with 6 years' resting. In this period the controls improved to a growth rate of 1·9 cm. per annum (part of which may have been due to increased poaching), while the manured plots did not quite maintain the rate of growth under full manuring, but fell back to 2·7 cm. per annum. Table 5 gives details of the individual experiments, which were remarkably consistent considering the variation in sites. The main new feature emerging from the last series of measurements is the better growth from the two treatments receiving phosphorus.

Acknowledgements.—The authors' acknowledgements are due to Dunlop Plantations, Ltd., for permission to publish this paper.

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(*Received 3 May 1954*)

THE CONTROL OF ARISTIDA AND OTHER ANNUALS IN KENYA RIFT VALLEY PASTURES

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IN 1946–7 a mass invasion of an annual grass, *Aristida keniensis* Henrard (which is a local species closely allied to the widely spread *Aristida adscensionis* L.), was observed in star grass pastures on the plains in the Lake Elmenteita area, and in other parts of Kenya. As it was feared that the invasion could be of a lasting or even of a permanent nature, experiments were commenced to discover the factors affecting the growth of Aristida and to investigate management technique suitable for the suppression of Aristida and restoration of star grass. The experiments commenced in July 1947 and were completed in March 1951, and after the treatments had been discontinued the plots were given a rest which lasted one growing season; the final records were taken in October 1951.

Experimental

The experimental plots were situated west of Lake Elmenteita at an altitude of 6,200 ft., where the plains normally have a cover of star grass (*Cynodon dactylon*, and to a much lesser extent *C. plectostachyum*). The experimental area was flat and very gently sloping towards the lake. The soil was light-grey in colour, almost structureless, light in texture and somewhat alkaline, with a sheet of solid, although not very hard, rock underlying the top-soil. The rock was about 6 in. thick and lay at a depth varying from 9 in. in the north-east corner of the experimental area (plots 7 and 8) to 40 in. in the south-west corner (plots 9 and 10). The distribution of Aristida in the plots before the commencement of the treatments was apparently connected with the depth of soil above the rock, there being much more Aristida and less star grass in places where the rock was nearer to the surface.

In August 1947, prior to the commencement of the experiment, the vegetation of the plots was briefly described and mapped and at that time the grass sward consisted mostly of star grass and *Aristida keniensis* in various proportions (see map, Fig. 1); *Digitaria scalarum* (couch grass), *Sporobolus marginatus*, and *Chloris gayana* (Rhodes grass) were also present in noticeable quantity. Couch grass grew in colonies usually mixed with the star grass and in some plots it formed a considerable portion of the herbage. *Sporobolus marginatus* formed pure colonies of low growth in small shallow pans while Rhodes grass occurred in rare colonies or as isolated tufts. Of the annual grasses *Chloris pycnothrix* (false star grass), *Eragrostis barrelieri*, and *Panicum atrosanguineum* were common and locally numerous.

Two annual species of legumes (*Crotalaria vogelioides* and *Medicago*

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laciniata) were rather prominent, the latter occurring often in extensive colonies.

Perennial herbs also occurred and were numerous in plots Nos. 11,

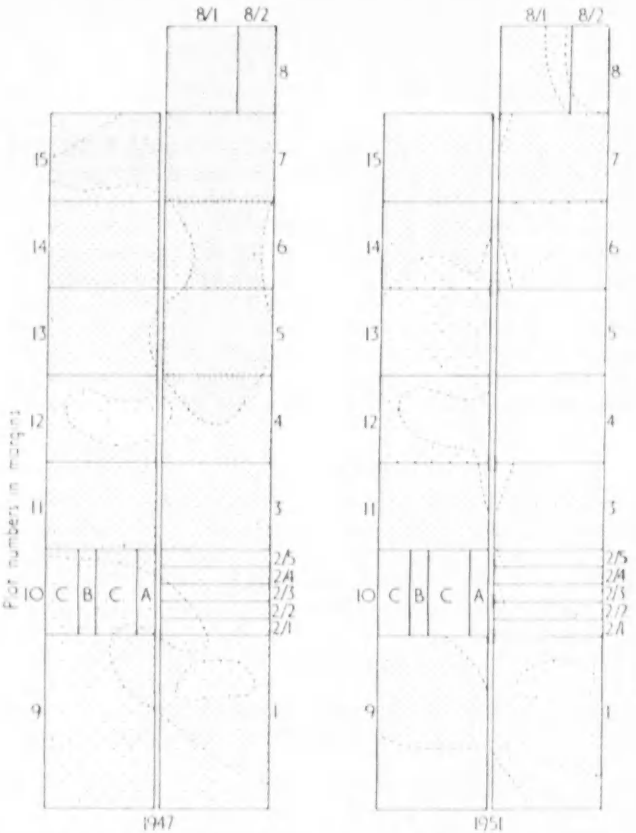

FIG. 1. Sketch map of experimental grazing plots at Elmenteita, Kenya. Estimated proportion of Aristida and other annuals in grass herbage

Under 20%
20%—40%
40%—60%
Over 60%

13, 14, and 15. They were mainly *Melhamia abyssinica*, *Pavonia* sp., *Priva leptostachya*, *Sida rhombifolia*, and *Hypoestes verticillaris*. Annual herbs were not prominent in 1947 excepting *Asystasia schimperi* and *Brassica schimperi*.

During the four years of the trial the grass cover of the plots underwent certain changes which were recorded by general visual observations

and in permanent transects. The transects were normally 100 ft. long and 8 in. wide and the proportion of the main grass species was estimated in each portion of the transect with uniform herbage. The weighted mean percentage was then calculated. Herbs were not considered in the transects. In each of the 10-acre plots two 100-ft. long transects were laid out and in the larger plots (20 acres) three transects were used. Transect readings were done once a year and at the same time of year, except in plots which were grazed bare just before reading, where a record was taken 2 months later instead.

The rainfall at Elmenteita during the experiment is shown in Table 1.

TABLE 1. *Monthly Rainfall at Elmenteita, Kenya*

	Average for 40 yrs.	*1947*	*1948*	*1949*	*1950*	*1951*
January	0·72	1·44	0·96	0·00	2·91	0·08
February	0·94	1·91	0·02	0·20	0·13	0·21
March	2·38	3·08	3·20	0·54	1·89	2·48
April	4·60	5·09	3·29	2·47	4·11	8·94
May	2·73	2·04	4·75	4·50	2·48	1·35
June	2·27	2·52	2·81	1·89	1·89	3·31
July	2·80	2·96	3·43	1·45	1·65	2·40
August	2·88	2·81	3·30	4·64	2·14	3·00
September	2·35	2·09	4·65	3·12	2·40	2·79
October	1·40	0·96	0·86	0·87	1·27	1·92
November	1·99	1·43	1·30	0·62	0·86	1·78
December	1·08	2·96	0·99	1·38	0·43	4·54
Total	26·14	29·29	29·56	21·68	22·16	32·80

The experiment included the following treatments:

A. Permanent grazing of cattle and sheep at a rate or intensity normally used in the area.

B. Seasonal grazing of cattle, each plot being grazed at the same period every year as follows:

1. onset of the rains;
2. middle of the rainy season;
3. late in the rainy season;
4. early in the dry season;
5. dry season.

Two densities were applied in seasonal grazing:

(*a*) light grazing: four head for 60 days in a 10-acre plot = 15 acres per head per year, and

(*b*) heavy grazing: twenty head for 60 days (or less if grazed bare and no grazing available) in a 10-acre plot, or approximately 3 acres per head per year.

C. One 10-acre plot was divided into five sub-plots in which heavy seasonal grazing was followed by harrowing.

D. Burning at the beginning and at the end of the rains as separate treatments.

E. Mowing before and after Aristida seeding as separate treatments.
F. Complete protection.

The trials were considered as preliminary and the treatments were not replicated.

The actual treatments were as follows:

Plot No.	*Size in acres*	*Treatment*
		A. Permanent Grazing
1	20	Permanent grazing of sheep. Fifteen head from 11 August 1947 to 26 March 1951.
9	20	Permanent grazing of cattle. Three head from 11 August 1947 to 26 March 1951.
		B. Heavy Seasonal Grazing of Cattle
3	10	Twenty head in April–May. 1947—16 days; 1948—44 days; 1949—36 days; 1950—36 days.
2/2	2	Four head in April–May with subsequent harrowing. 1948—44 days; 1949—36 days; 1950—36 days.
4	10	Twenty head in June–July. 1947—16 days; 1948—57 days; 1949—64 days; 1950—28 days.
2/3	2	Four head in June–July with subsequent harrowing. 1948—57 days; 1949—64 days; 1950—28 days.
5	10	Twenty head in August–September. 1947—59 days; 1948—63 days; 1949—58 days; 1950—37 days.
2/4	2	Four head in August–September with subsequent harrowing. 1948—63 days; 1949—58 days; 1950—37 days.
6	10	Twenty head in October–November. 1947—42 days; 1948—59 days; 1949—42 days; 1950—41 days.
2/5	2	Four head in October–November with subsequent harrowing. 1948—59 days; 1949—42 days; 1950—41 days.
7	10	Twenty head in December–February. 1947–8—49 days; 1948–9—60 days; 1949–50—24 days; 1950–1—35 days.
2/1	2	Four head in December–February with subsequent harrowing. 1947–8—22 days; 1948–9—60 days; 1949–50—24 days; 1950–1—35 days.
		C. Light Seasonal Grazing of Cattle
11	10	Four head in April–May. 1947—60 days; 1948—42 days; 1949—63 days; 1950—64 days.
12	10	Four head in June–July. 1947—42 days; 1948—59 days; 1949—70 days; 1950—58 days.
13	10	Four head in August–September. 1947—58 days; 1948—63 days; 1949—57 days; 1950—67 days.
14	10	Four head in October–November. 1947—42 days; 1948—59 days; 1949—70 days; 1950—58 days.
15	10	Four head in December–February. 1947–8—49 days; 1948–9—79 days; 1949–50—24 days; 1950–1—60 days.
		D. Burning
8/1	6	Burning early in dry season. Burnt 15 October 1947 and 6 January 1949.
8/2	3	Burning at the beginning of the rains. Burnt 23 March 1948. Insufficient growth for burning in 1949–50.

Plot No.	*Size in acres*	*Treatment*
		E. Mowing
10A	1	Mowing before Aristida seeding. Mown 20 May 1948 and 7 August 1948. Insufficient growth for mowing in 1949–50.
10B	1	Mowing after Aristida seeding. Mown 15 October 1948 and 2 December 1950. Insufficient growth for mowing in 1949.
		F. Complete Protection
10C	8	Complete protection.

Although the trial was designed to investigate the problem of suppression and eradication of Aristida in star grass pastures, other useful information concerning the effect of various treatments on the herbage was obtained. This information, and some notes on comparative palatability of the main grass species of the area, are briefly outlined below.

Grazing Preference

On the experimental plots the cattle showed the following preference in grazing various grasses:

(*a*) *Sporobolus marginatus*. If available, the cattle definitely preferred this grass to any other species of importance and it was grazed close to the ground.

(*b*) *Digitaria scalarum* (couch grass) was usually eaten next unless young fresh growth of Aristida was available.

(*c*) Aristida. The young growth was eaten greedily but at later stages, when producing seed, it was usually untouched by cattle. Old dry Aristida, with all seed shed, was again comparatively well grazed and was then preferred to the old growth of star grass.

(*d*) Star grass. When it was young and green star grass was well grazed, but when hard stems had formed it was grazed less willingly and preferred only to Aristida at the seeding stage or to mature Rhodes grass. In plots of heavy seasonal grazing, when no other grass was available it was almost entirely consumed and only the hard stolons remained.

These observations refer only to comparative palatability of the main species of the plots without taking into account other aspects of grazing value. In spite of the lesser palatability of star grass compared with couch grass and *Sporobolus marginatus* it has an advantage over these two grasses in being much more productive, and over the Aristida in being a perennial.

Effects of Treatments on Herbage

These effects are given in Table 2, in the form of ratios of perennials to annuals based on the transect readings. They are also shown on a map of the plots at the beginning and at the end of the experiment (Fig. 1). The ratios obtained in the transect readings show the changes that took place in the proportion of perennials and annuals along the transects as

the experiment progressed. Because of the variability of the herbage, however, they may not represent exactly the proportion in the plot as a whole and that which is shown on the map.

TABLE 2. *Ratio of Perennials to Annuals in Grass Herbage. Grazing Experiments at Elmenteita, Kenya*

(*Based on transect readings*)

Plot No.	*Treatment (details in text)*	*1947*	*1948*	*1949*	*1950*	*1951*	*1951 after rest*
				Permanent Grazing			
9	Cattle	67:33	81:19	90:10	97:3	95:5	70:30
1	Sheep	58:42	66:34	69:31	89:11	91:9	75:25
				Heavy Seasonal Grazing			
3	April–May	44:56	44:56	59:41	55:45	92:8	61:39
2/2	Same + harrowing	41:59	41:59	43:57	46:54	94:6	69:31
4	June–July	44:56	50:50	42:58	66:34	95:5	74:26
2/3	Same + harrowing	47:53	65:35	57:43	65:35	98:2	78:22
5	August–September	39:61	84:16	91:9	92:8	99:1	91:9
2/4	Same + harrowing	58:42	87:13	95:5	94:6	100:0	97:3
6	October–November	43:57	75:25	91:9	96:4	96:4	80:20
2/5	Same + harrowing	33:67	46:54	74:26	81:19	94:6	71:29
7	December–February	35:65	59:41	71:29	81:19	87:13	68:32
2/1	Same + harrowing	61:39	79:21	60:40	70:30	93:7	85:15
				Light Seasonal Grazing			
11	April–May	41:59	60:40	64:36	89:11	95:5	69:31
12	June–July	58:42	78:22	85:15	94:6	96:4	74:26
13	August–September	37:63	75:25	85:15	99:1	92:8	76:24
14	October–November	47:53	73:27	76:24	66:34	79:21	59:41
15	December–February	32:68	56:44	46:54	64:36	66:34	36:64
				Burning			
8/1	After rains	38:62	84:16	91:9	97:3	98:2	74:26
8/2	Before rains	51:49	94:6	99:1	100:0	100:0	94:6
				Mowing			
10A	Before Aristida seeding	60:40	84:16	94:6	100:0	96:4	77:23
10B	After Aristida seeding	73:27	87:13	96:4	95:5	97:3	81:19
				Complete Protection			
10C		77:23	89:11	100:0	100:0	98:2	88:12

Changes in individual plots are discussed below with reference to the chief species concerned.

Permanent grazing of cattle.—(Plot No. 9: 6·7 acres per head per year). At the beginning of the experiment this plot had better grass than any other plot in the trial, with over 60 per cent. of star grass and about 30 per cent. of Aristida. Under grazing the proportion of Aristida steadily

decreased and in 1950 only 3 per cent. was recorded in transects. During the 1951 rains the amount of Aristida increased again and reached over 20 per cent. and together with other annuals it again formed about 30 per cent. of the grass. A considerable amount of couch grass was observed in this plot and it was increasing during the experiment.

Every year the cattle selectively grazed the young green growth from the same places and the herbage gradually became uneven, with bare patches. In 1951, the first wet year since 1948, the bare places were mostly invaded by annual grasses (Aristida and *Panicum atrosanguineum*) and annual herbs (*Leucas martinicensis*, *Crambe kilimandscharica*, &c.). In some parts of the plot these herbs formed well over 50 per cent. of the total herbage.

In general, 4 years of permanent grazing produced an adverse effect on the herbage, which became patchy, with numerous bare places that were invaded by annuals in the first wet year.

Permanent grazing of sheep.—(Plot No. 1: 1·3 acres per head per year). In 1947 the plot allocated for this treatment had a large proportion of star grass and a comparatively low proportion of Aristida. The herbage was only slightly inferior to that of plot No. 9, which was used for permanent grazing of cattle. In 1948–50 the proportion of Aristida decreased very slowly and in 1951 it again formed about 20 per cent. of the total grass herbage.

In general, the effect of permanent grazing of sheep on the herbage was rather similar to the effect produced by permanent grazing of cattle. The grass became patchy and many bare places appeared, which, in 1951, were invaded by annual grasses and herbs.

Heavy seasonal grazing.—In this treatment the intention was to keep twenty head of cattle in a 10-acre paddock for 60 days (= 3 acres per head per year). However, in many instances the grass was eaten bare in 30–45 days (= 4·5–6 acres per head per year) and the cattle had to be removed.

The plots were grazed bare and only the most unpalatable parts of certain grasses, such as old star grass stolons, were left uneaten. A few unpalatable herbs also remained. It was feared that these bare plots would not recover and that the perennial grass would be destroyed. After a rest was given to all plots in the rainy season of 1951, which had good rains, the grass recovered well and most of the plots of heavy seasonal grazing produced better grass than at the beginning of the experiment.

Initially the plots under heavy seasonal grazing had a large proportion of Aristida and, in most cases, rather a small proportion of star grass.

The effect of such treatment on the herbage varied in the different plots and was connected with the season of grazing, as the following notes show.

(*a*) *Grazing early in wet season* (plot No. 3). The plot was heavily grazed every year from the beginning of the rains, usually from the end of April. During the wet seasons of 1948, 1949, and 1950 star grass did not recover well, remaining thin and somewhat patchy. A large proportion of Aristida remained in this plot in 1948, 1949, and 1950, but early

in 1951 the proportion of Aristida dropped rapidly to only 39 per cent. However, later in 1951, the amount of Aristida increased and another annual grass, *Panicum atrosanguineum*, increased considerably, these two annuals forming about 40 per cent. of the herbage in October 1951.

It seems that repeated and heavy grazing in the early part of the rainy season severely punished the young growth of grass so that it was unable to recover during the remaining part of the season: hence the adverse effect on the herbage.

(*b*) *Grazing in the middle of the wet season* (plot No. 4). Grazing began at the end of May or in June, and after grazing the grass did not recover in the same season. Early in the wet season of the following year it gained vigour and recovered better than under treatment (*a*). The initial high proportion of Aristida remained in 1948 and 1949 but in 1950 it began decreasing and in the early part of the 1951 rains there was very little Aristida left in the plot. Later in 1951 its proportion again increased and the final transect reading in October 1951 showed 20 per cent. of Aristida. The proportion of star grass, however, had not increased in 1950–1 and the Aristida was replaced chiefly by couch grass. Annual herbs and *Panicum atrosanguineum* did not invade this plot in 1951 and the grass remained more uniform and dense than in the plot grazed earlier in the season.

It seems that during 4 years of the trial the grazing in this plot improved slightly.

(*c*) *Grazing late in the wet season* (plot No. 5). Grazing usually began in August and the plot was grazed bare every year. Before the next grazing the grass recovered better than under treatments (*a*) and (*b*) and the proportion of Aristida decreased very rapidly; the transect readings recorded 57 per cent. of Aristida in 1947, 16 per cent. in 1948, and 8 per cent. in 1949. Even in October 1951, after a rest during the wet season, the proportion of Aristida remained very low. Other annual grasses were sparse but annual herbs appeared early in the rainy season of 1951, disappearing again towards the end of the season.

Initially this plot had a poor herbage with abundant Aristida, but at the end of the trial it produced very good grazing and became one of the best plots, evenly covered with dense star grass.

(*d*) *Grazing early in the dry season* (plot No. 6). Grazing began usually in October and the grass recovered rather well during the rainy season of the following year. In the first 2 years the proportion of Aristida decreased fairly rapidly, but slower than under treatment (*c*), and the amount of Aristida and other annuals was greater after the rest in 1951. Early in 1951 annual herbs were numerous, but they disappeared towards the end of the rains and in October 1951 the plot was covered with rather tall and even, but not dense, star grass mixed with couch grass and about 10 per cent. (by transect) of Aristida. In general the grass in this plot improved after 4 years of treatment.

(*e*) *Grazing in the dry season* (plot No. 7). Grazing normally began in December, and in 1947 65 per cent. of Aristida was recorded in transects. In the years 1948–50 the amount of Aristida decreased rather slowly and even in July 1951, when nearly all other plots had virtually no Aristida,

the proportion of Aristida in this plot was about 15 per cent. At the time of the last recording Aristida formed just under one-third of the herbage. Other annual grasses were not recorded in this plot in noticeable quantity, but small annual herbs were rather numerous in July 1951. Later on they disappeared and the herbage consisted of a rather uniform and tall but not dense sward of star grass, with a considerable admixture of Aristida. After treatment it could be said that the herbage in this plot improved slightly.

This account of the changes in the herbage under heavy grazing at different seasons shows that grazing late in the wet season produced the best results, with considerable improvement of the grass. Grazing in the middle part of the wet season and early in the dry season also improved the herbage but to a lesser extent. Dry-season grazing produced only very slight improvement, and grazing at the beginning of the rains produced an adverse effect on the grass cover resulting in patchy and weak grass with abundant annuals. Heavy seasonal grazing produced better results than permanent grazing. It should be noted that the rate of seasonal grazing was higher than that of the permanent grazing and the plots under the former treatments were initially somewhat inferior to those of the latter. We believe that on grass of the same quality heavy seasonal grazing would produce still better results compared with permanent grazing.

Heavy seasonal grazing with subsequent harrowing.—Plot No. 2 was divided into five paddocks which were given the same grazing treatment as plots 3–7 but with harrowing after the grazing. The harrowing did not produce any marked effect on the herbage and the grass in these paddocks was essentially the same as in corresponding plots which were not harrowed. Only the proportion of couch grass somewhat increased in the harrowed plots towards the end of the experiment.

Light seasonal grazing of cattle.—(Plots 11–15: 15 acres per head per year.) Light grazing at different seasons produced a more consistent effect on the herbage than heavy grazing and after 4 years of treatment resulted in patchy, uneven grass cover in all plots. The cattle ate the more palatable grasses leaving the less palatable herbage. Patches of old, coarse star grass and dry mature Aristida interspersed with bare patches were observed every year and were characteristic of the plots of light seasonal grazing. The proportion of Aristida in the herbage decreased from 1948 to 1950 at apparently the same rate as in the surrounding pastures and slightly increased again in 1951. The increase was more pronounced in plots grazed in the dry season. In the wet season of 1951, when all plots were given a rest, *Panicum atrosanguineum* invaded the plots, particularly those grazed in the dry season, where it comprised about 30 per cent. of the grass herbage. The amount of herbs also increased in this plot.

In general, light seasonal grazing produced more patchy and inferior herbage, and no marked effect due to the season of grazing was observed.

Burning.—Two treatments were used: (*a*) (plot No. 8/2) burning at the beginning of the rains, and (*b*) (plot No. 8/1) burning early in the dry season. The plot under treatment (*a*) was actually burnt only once, in

1948, and under treatment (*b*) only twice, in 1947 and 1949, because in other years there was insufficient growth to allow burning. At the beginning of the experiment the plots had a large proportion of Aristida, varying from 45 to 60 per cent. The grass was fairly uniform and after the first fire the Aristida population decreased very rapidly. In 1950 Aristida had almost entirely disappeared but in 1951 it reappeared, mainly in the plot burned at the beginning of the rains. It seems that if a quick suppression of Aristida is needed one good fire may be sufficient, although the effect of burning may be only of a temporary nature.

Mowing.—(Plots No. 10A and 10B). Parts of plot No. 10 were mown twice a year either before or after the Aristida had produced seed and both treatments seem to have a rather similar effect on the grass. At the beginning of the experiment the plot had a good grass cover inferior only to the grass of the plot No. 9, star grass forming 60–75 per cent. of the even and dense grass herbage and Aristida 20–40 per cent. After the first 2 years of the trial the proportion of Aristida decreased rapidly, and in 1950 there was practically no Aristida left in the plot, but in the rainy season of 1951 Aristida reappeared. In 1948–9 star grass remained dense and was recovering well after mowing, but in the following year it became thin and did not recover satisfactorily and the mowing had to be discontinued because of the lack of growth. Even after the good rains of 1951 star grass remained thin and weak and a large amount of annual herbs appeared. In general, repeated mowing, weakening the star grass, encouraged the appearance of annual herbs.

Complete protection.—(Plot No. 10C). A portion of plot No. 10 was under permanent rest, and before the experiment started the protected part of the plot had an even and dense cover of star grass with only 20–25 per cent. of Aristida. After the first 2 years of rest Aristida disappeared completely and only a small quantity of it reappeared in 1951. Star grass remained rather uniform throughout the experiment but there was little fresh growth during the rains. After the 1951 rains annual herbs appeared and in some places they formed more than a half of the total herbage. The herbs, however, were low and not very conspicuous. It seems that the long rest did not improve the grass cover.

Discussion

The proportion of undesirable annual grass—*Aristida keniensis*—in the herbage of the experimental plots varied markedly from year to year. In 1948, 1949, and 1950, the last two being comparatively dry years, there was a general decrease of Aristida showing that the invasion of Aristida was only of a temporary nature probably connected with rainfall fluctuations. In 1950 the proportion of Aristida dropped to under 10 per cent., which is normal in local pastures. In 1951, which was a wet year, the proportion of Aristida increased again but remained lower than in 1947.

The rate at which the proportion of Aristida decreased in the experimental plots in 1948–50 was connected with the treatments. The most spectacular decrease of Aristida was observed after burning, in plots

which were particularly severely invaded. Other treatments which also resulted in quick suppression of Aristida were: mowing, complete protection, heavy grazing late in the wet season and early in the dry season. The treatments which resulted in a slow and often incomplete elimination of Aristida were: permanent grazing of cattle and sheep, light and heavy grazing in the dry season, and heavy grazing at the beginning of the rains.

In 1951, following the good rains, the proportion of Aristida increased again and in certain plots *Panicum atrosanguineum* and some annual herbs became abundant. Here again different treatments produced different results and while under certain treatments the herbage remained comparatively free from annuals, under other treatments the annuals became abundant.

It may be assumed that if after a few dry years star grass has been weakened by drought, the resultant bare places are invaded by Aristida in the first good rainy season. Other annuals, grasses or herbs may appear in wet years instead of or together with Aristida, as happened in 1951.

The invasion of annuals in 1951, although less severe than in 1947, indicates that there is a danger of reinvasions in the future, so that the problem of suppression of Aristida and other annuals can be divided into two parts: (*a*) how to suppress Aristida when it has already invaded the pastures, and (*b*) how to prevent further invasions. While the first part of the problem can be solved by some special, temporary measures, the second part involves the whole system of pasture management and is, probably, the more important part of the problem.

(*a*) The results of the trial suggest treatments which can be used for suppression of Aristida if it has already invaded local star grass pastures. It seems that burning is the most effective measure, as far as we can judge from the effect obtained in a trial of rather short duration. In the burnt plots the proportion of Aristida had already decreased very rapidly in the year following the first burning. In 1947 there was 53 per cent. of Aristida in transects of both the burnt plots and in 1948 its proportion dropped to 10 per cent. As Aristida invades pastures mainly in wet years a good fire can easily be secured.

Under mowing and resting only a small amount of Aristida was observed in the second year of the trial. However, in plots under this treatment the initial proportion of Aristida was much smaller than in the burnt plots. Under local ranching conditions mowing is not a measure that can easily be applied.

Another answer to the problem of quick suppression of Aristida may be a heavy concentration of cattle late in the rainy season. In plot No. 5, grazed late in the rainy season, the proportion of Aristida in the herbage dropped during the first year of the trial from 57 to 16 per cent.

(*b*) An essential part of the Aristida problem is the creation of conditions under which an invasion would be less probable and, if it occurred, less severe. Observations during the trial showed that if a uniform and sufficiently vigorous cover of perennial grasses, including star grass, is developed and maintained, the annuals have no room to develop and their population is very small even in wet years. If, on the other hand,

the herbage becomes uneven and patches of perennial grasses are interspersed with partially bare places, the latter are open to invasion by annuals which may become abundant in wetter years, though in drier years they are usually not conspicuous.

Of the grazing treatments used in the trial, permanent grazing by cattle, and to a lesser extent, by sheep, resulted in a more patchy cover than at the beginning of the experiment. Although in 1951 the proportion of Aristida in plots under these treatments did not reach the level observed in 1947, the invasion of other annuals, particularly herbs, kept the population of annuals at a high level. Light seasonal grazing also resulted in rather patchy herbage with numerous annuals which in 1951 invaded former bare and partially bare places. This, we believe, was due to highly selective grazing by the cattle eating the young and more palatable perennial grass repeatedly from the same places and severely punishing and eventually killing it.

Under heavy seasonal grazing at the beginning of the rains, when very young grass was grazed for 40–60 days, patchy and weak grass developed. Heavy grazing late in the dry season did not suppress Aristida to a desirable degree, though the grass cover was comparatively even. However, heavy grazing at other seasons resulted in the improvement of the herbage. The sward of perennial grasses became uniform and comparatively vigorous, the amount of annuals decreased, and, what is particularly important, they were less abundant in 1951 as compared with other grazed plots. Heavy grazing late in the wet season produced particularly good results. Heavy seasonal grazing in general showed better results than permanent or light seasonal grazing, not only in the suppression of Aristida and in preventing the increase of annuals in wetter years, but also in developing a better and more uniform grass cover, palatable at the time of grazing.

It would appear from the experiment that an invasion of Aristida could be dealt with promptly by the use of fire, and reinvasions checked by using a simple method of deferred rotational grazing under a sufficiently high rate of stocking.

Summary

Grazing trials were organized in 1947 near Lake Elmenteita, Rift Valley, Kenya, in order to find a suitable management technique for suppressing *Aristida keniensis*, an undesirable annual grass which invaded star grass pastures. The treatments used in the trial included permanent grazing of cattle and sheep, seasonal grazing of cattle at two rates, burning, mowing, and complete protection. The trial lasted 4 years and was completed in 1951.

The proportion of Aristida in the herbage during the experiment was lower in dry years and higher in wet years, and invasions of annual pasture weeds are more likely to occur if a series of dry years is followed by a wet year.

Of the treatments used in the trial, burning, mowing, complete protection, and heavy grazing late in the wet season and early in the dry season, resulted in a marked decrease of Aristida.

Heavy grazing at certain seasons maintained an even and dense cover of star grass (*Cynodon dactylon*) and this prevented the pasture from suffering another invasion of annuals such as was observed on other plots in the wet year of 1951.

It is concluded that to avoid invasions of annual pasture weeds, including Aristida, a system of grazing rotation under sufficiently heavy stocking should be applied.

Acknowledgement.—We wish to record our thanks to Delamere Estates for the use of their land and for the help afforded by their staff during the experiment.

(*Received 31 March 1954*)

TWINNING IN OSSIMI SHEEP

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INVESTIGATING the causes of variation in twinning in Egyptian sheep, as well as assessing their effects, provides the basic information which the breeder needs in order to plan an improvement programme for this character. In the present investigation, some of the important non-genetical factors were studied. The effects of year, time of mating, age of the ewe, type of birth, inbreeding, and the effect of sire on lambing percentage, were examined. The heritability of twinning was also estimated, since it decides the breeding plan that would best lead to a rapid genetic improvement in twinning in sheep.

Material and methods.—The data used in this investigation were taken from the breeding records of the flock of Ossimi sheep belonging to the Animal Breeding Department, Faculty of Agriculture, Giza. The study included all lambs born on the farm from 1934 to 1952. It comprised 1,113 lambs, of which 583 were males and 530 were females. There were 715 lambs born as singles, and 398 born as twins.

The coefficients of inbreeding for all lambs were calculated, using Wright's formula [1]. Analysis of variance and the significance test for differences between means were calculated according to Snedecor [2]. The heritability estimate for twinning was estimated by intra-sire regression of lambing averages of daughters on those of dams, based on the first two lambings [3].

Results

Effect of year.—Table 1 shows the lambing percentages for ewes in the different years from 1940 on.

TABLE 1. *Effect of Year on Lambing Percentage*

Year	*Lambing %*	*Year*	*Lambing %*	*Year*	*Lambing %*
1940	106	1945	119	1950	135
1941	109	1946	123	1951	143
1942	131	1947	119	1952	122
1943	113	1948	135		
1944	118	1949	142		

Lambing percentages varied from 106 to 143 and the differences between years were statistically significant. Although the flock was started in 1934 it was not stabilized until 1940, after which a gradual increase in lambing percentage occurred till the maximum was reached in 1951. A year-to-year variation in twinning has been reported by many investigators, notably Marshall and Potts [4] and Desai and

Winters [5], who attributed it mainly to changes in feeding and management.

Effect of time of mating.—For studying the influence of time of mating on twinning, lambings were recorded according to their incidence on a fortnightly basis, and the scale was then moved back 154 days to give the approximate dates of matings. Since about 80 per cent. of the lambs were dropped during the months of October, November, and December,

TABLE 2. *Effect of Time of Mating on Lambing Percentage*

Time of lambing		*Time of mating*		*Lambs born*	*Lambing %*
October	1–15	May	1–15	116	143
	16–30		16–30	204	144
November	1–15	June	1–15	302	139
	16–30		16–30	139	124
December	1–15	July	1–15	57	128
	16–30		16–30	32	113

the study was confined only to these months, which in fact constitute the lambing season in most parts of the country.

Results obtained on the relationship between time of mating and twinning are shown in Table 2.

It was found that the highest percentage of lambing occurred during October and the first half of November, the figures being 143 and 139 per cent. respectively. This coincides with the matings that took place in May and the first half of June. The result is in agreement with the

TABLE 3. *Effect of Age of the Ewe on Lambing Percentage*

Sequence of lambing	*No. of ewes*	*No. of lambs born*	*Lambing %*
1	303	336	111
2	228	268	118
3	144	203	141
4	92	108	117
5	70	90	130
6	34	50	145
7	16	22	137

findings of Marshall and Potts [4], Biegert [6], Johansson and Hansson [7], and Hammond, Jr. [8], who concluded that the incidence of twinning is greater in the first half of the mating season.

Effect of age.—Since the ages of many of the ewes were not known, the sequence of lambing was used for studying the effect of age on lambing percentage as shown in Table 3. Ewes in this flock generally lamb for the first time when they are about 2 years of age, and continue to lamb regularly once every year.

It is evident from Table 3 that twinning increased as age advanced,

and it reached the maximum when ewes were about 7–8 years of age (from the 6th to the 7th lambing). This agrees well with the results obtained by Jones and Rouse [9], Roberts [10], and others [4, 5, 6].

Effect of type of birth.—In this flock selection was mainly based on twinning, and neither stock ewes nor rams were kept in the flock unless they were either twins themselves or of twin origin. Therefore it was thought desirable to investigate the effect of type of birth of the ewe on twinning.

TABLE 4. *Effect of Inbreeding on Lambing Percentage*

Coefficient of inbreeding	*No. of ewes*	*No. of lambings*	*No. of lambs born*	*Lambing %*
0 . . .	193	734	910	124
1·0–6·0 . .	18	42	56	133
6·1–12·0 . .	6	17	27	159
12·1–18·0 . .	12	30	35	117
18·1–24·0 . .	..	..	..	..
24·1–30·0 . .	19	29	33	114

Out of 303 ewes bred in the flock, only 81 were born as twins, 23 were of uncertain type of birth, and 199 were born as singles. The average number of lambings in the twin group of ewes was 3·01 and the lambing percentage came to 120 per cent. The single ewes gave 3·03 lambings and their lambing percentage was 118. Comparison of these figures showed that there was no significant difference in the twinning ability

TABLE 5. *Effect of Sire on Lambing Percentage*

Source of variance	*Sum of squares*	*D.F.*	*M.S.*
Between sires	90·34	8	11·27†
Within sires	7·37	405	0·02
Total	97·71	413	..

† Significant at P = 0·01.

of the two types of ewes, in either the length of productive life or the number of lambs dropped. This result, however, is not in agreement with the findings of Desai and Winters [5] and Kiser and Christagau [11], who found that ewes born as twins gave birth to more lambs than did single-born ones.

Effect of inbreeding.—Ewes born and bred on the farm were classified into seven groups according to their coefficients of inbreeding, which ranged from 0 to over 30 per cent. It was noticed that there was no consistent trend in lambing percentage of ewes with a rise in the coefficient of inbreeding (Table 4). The highest lambing percentage obtained (159 per cent.) was that for ewes having an inbreeding coefficient of from 6 to 12 per cent., followed by those having 1–6 per cent. inbreeding coefficient.

Effect of sire.—The effect of sire was studied, using analysis of variance of the progeny of nine rams (Table 5).

It is evident from Table 5 that the rams differed very significantly in respect of the frequency of twinning in their offspring. This is rather an indirect effect on twinning since ewes are responsible for the number of ova shed. It may be inferred that the effect is a result of differences in the fertilizing capacity of different rams. Ossimi rams have been found to vary significantly in their semen qualities [12].

However, this result is analogous to the findings of Geurlich [13] with human twins, namely, that the progeny of certain sires comprised more twins than that of others. Such an effect of the sire could be accounted for either by hereditary differences between males or by some environmental factors which make certain rams more liable to get twins in their progeny.

Johansson and Hansson [6] found a small but highly significant correlation between the lambing potentiality of ewes bred by the same sire. They suggested that the differences between daughter groups were probably to some extent environmental. Desai and Winters [5], on the other hand, found no significant effect from the sire. This result was mainly due to the fact that their data were from selected ewes and the selection caused the removal of some of the deviation due to sire.

Although the approach of these workers was different from that of the present investigation, yet they denote the possibility of a moderate genetic effect of the sire on twinning.

At any rate, the importance of selecting sires on a basis of their ability to produce twins should not be overlooked. If progeny testing is sought for, it should be carried out following a plan especially designed to overcome environmental effects.

Heritability of twinning.—The number of daughter-dam pairs used in estimating the heritability of this character was 140, while the number of sires was eight. The regression of daughters on dams was found to be 0·0181, yielding a heritability estimate of 0·0362, which is in close agreement with that reported by Desai and Winters [14] on different breeds of sheep in the U.S.A. The estimates reported by Johansson and Hansson [6] in Sweden were, however, higher than that of the present study.

No correction for the effect of inbreeding was made in the heritability of twinning, since the average coefficient of inbreeding for the ewes used in calculating the heritability was not very high.

Discussion

Increasing the incidence of twinning in sheep, either through the control of environmental factors affecting this character, or by improving the genetic potentialities of animals, will undoubtedly lead to increased mutton production.

In the present flock the average lambing percentage was found to be 120 per cent., which is rather low compared with the percentages reported by Chapman and Lush [15], Terrill and Stoehr [16], and others [5] 6, for non-Egyptian breeds of sheep.

There were significant differences between years in lambing percentage. This is to be expected since the amount of food available varies from year to year. Workers in other countries have shown that flushing ewes helps in increasing the number of lambs born [4, 17], and in the years when lambing percentage was low the amount of food available for ewes was probably not enough to cause a flushing effect.

It was found that lambs were dropped during nearly every month of the year, but owing to economic and agricultural considerations the lambing season in Egypt usually takes place during October, November, and December. The present study showed that the highest percentage of twinning occurred during October and the first half of November. As those lambings were the result of mating ewes in May and June it is therefore advisable to restrict the mating season to that period of the year.

The feeding condition of the ewes during the months of May and June was doubtless responsible for the results thus obtained, since a high standard of nutrition encourages the production of multiple ova. As the season advances the feeding conditions of Egyptian sheep become more severe, and multiple ovulation therefore occurs more seldom.

There was found to be a gradual increase in lambing percentage with increase in age, till a maximum was reached when the ewes were about 7–8 years of age. It should be borne in mind that differences in twinning percentages between animals of different ages may not be due solely to age, since selection was practised throughout all the period of the study. In fact, 25 per cent. of the ewes were culled after their first lambing, 28 per cent. after their second lambing, and 17 per cent. at the third lambing, thus leaving only 30 per cent. of the ewes to stay in the flock after the third lambing. Comparison between the Ossimi sheep and non-Egyptian breeds in this respect shows that the Ossimi ewes lamb for the first time at about 1 year older than the other breeds, although both of them reach their maximum lambing percentage at approximately the same age. This is due to the slower rate of growth of the Ossimi sheep.

The present flock of sheep was nearly closed to outside blood, and inbreeding has been heavily practised in its construction. The average inbreeding coefficient for the inbred lambs was 14·7 per cent. [18]. The twinning percentage for the inbred group was 128 per cent. compared with 124 per cent. for outbred ones. The result indicates that inbreeding did not affect this character significantly.

The type of birth (single or twin) of the ewes was found to be of no effect on lambing percentage. This result is contradictory to the findings of Desai and Winters [5].

There were significant differences between rams in the incidence of twinning in their offspring. Since Darwish [12] has shown that individual differences in semen characters (viability, concentration, motility) are highly significant in Ossimi rams, it is possible that these differences are responsible for the effect of sire on the incidence of twinning. However, this explanation does not seem to be entirely satisfactory, since the ovum is attacked by few spermatozoa and is fertilized by only one.

Further studies are needed to find out the exact role which the male gametes play in the frequency of twin lambs from both physiological and hereditary standpoints.

Whatever the explanation, there will be no harm in selecting rams according to their capacity to produce twins, whether it is measured directly (through their daughters) or indirectly (in their offspring). Progeny testing of sires could be suggested where the general influence of sires on the fertility of ewes is proved to be significant.

The heritability estimate obtained in this investigation, although very low (0·0362), yet agrees with that reported by Desai and Winters [5]. This low estimate indicates that phenotypic selection will not lead to a rapid improvement in twinning. The best breeding method for increasing lambing percentage is crossing different lines in the same breed or crossing the breed with other breeds outstanding in this respect. From the non-genetical point of view, improving the feeding conditions, especially before mating time, as well as choosing the appropriate time for mating, will lead to a considerable increase in twinning.

Summary

An investigation of factors affecting twinning, or lambing percentage, carried out on 1,113 Ossimi lambs collected between 1934 and 1952, gave the following results:

The lambing percentage over the whole of this period was 120 per cent.

There were significant differences between years in the lambing percentage.

Twins were dropped more frequently in those lambings resulting from matings occurring in May and the first half of June.

Age affected lambing percentage significantly: ewes reached their maximum in twin births at the age of 7–8 years.

The type of birth of the ewe had no effect on twinning.

There was no difference in the lambing percentage between inbred and outbred ewes.

There was a definite and significant indirect effect of sire on twinning.

The heritability of twinning was estimated as 0·0362.

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(*Received 2 April 1954*)

A TILLAGE STUDY IN KENYA COFFEE

PART I. THE EFFECTS OF TILLAGE PRACTICES ON COFFEE YIELDS

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WITH PLATE 5

The problems to be studied.—The main coffee-producing areas of Kenya lie on the south-east slopes of the Aberdare range. The soils are very deep, friable, lateritic clays, derived from massive sheet lava and classified as the Kikuyu Red Loam series. The lava has been dissected by streams into characteristic steep-sided ridges. Most of the plantations were established in the early years of the present century, the trees being planted in straight lines without regard to the contours, so that cultivation has been up and down slopes which sometimes exceed 20 per cent. Although these soils are inherently stable, sheet-erosion has been general and gullying has occurred on many plantations. This erosion has taken place mainly in the hotter and drier areas below an altitude of about 6,000 ft. Here coffee is grown without shade protection, and two-thirds of the soil surface is exposed alternately to severe desiccation and to the impact of tropical rainstorms. The steady decrease in the supply and reliability of manual labour intensifies the dangers of soil erosion, as the coarse cloddy tilth of the hand-hoe is replaced by the continuous off-contour furrows of the disk-harrow or plough.

The selection of tractor-mounted implements and of the optimum depth of tillage are both complicated by the presence of the vigorous surface root-mat of coffee, and its susceptibility to mechanical damage. A further point requiring study has been the effects of the subsoil tine. The 2 ft. of rich, loose top-soil, left by the indigenous vegetation of forest and bush, has been lost over parts of the plantation area, so that the uniform compact subsoil is covered in some places by only a few inches of dusty tilth. A number of hypothetical benefits have been claimed for the use of a subsoiler in these circumstances. Finally the intensity of weed growth is substantially increased by the dressings of weathered, dry, cattle manure obtained from native cattle pens on the open plains, and applied extensively to coffee plantations in these areas.

Details of field experiment.—This set of problems was combined for study in a 16-acre field experiment laid down in 1947 on the Coffee Research Station at Ruiru [1]. Three types of implement were compared; the forked hoe (forked *jembe*) was used as the best-known tillage treatment (t_0). It was compared with tractor-mounted disk-harrows (t_1) and the tractor-mounted three-furrow plough (t_2). These were tested at

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[Empire Journ. of Exper. Agric., Vol. 22, No. 87, 1954.]

three depths of cultivation, shallow (d_0) at 2 to 3 in., deep (d_2) at 5 to 6 in., and an intermediate combination (d_1) of shallow weeding with a single deep cultivation in dry weather. A heavy, trailed disk-harrow was required to achieve the deeper cultivations (t_1). Weed control policies comprised clean weeding (w_0), weeds slashed during the rains and cultivated at the onset of dry weather (w_1), and unrestricted weed growth during each rains, killed by cultivation only at the onset of dry weather (w_2). Subsoiling treatments were nil (s_0), all-row subsoiling every 4 years (i.e. one side of trees on alternate years) (s_1), and all-row subsoiling every 2 years (i.e. one side of trees subsoiled each year) (s_2). These four main factors were used in a $3 \times 3 \times 3 \times 3$ design, partially confounded to give nine blocks each of nine plots. All plots were split for the application of cattle manure. 3 to 4 tons per acre were given annually, as one 4-gallon tin per tree to one of each pair of sub-plots. Although small, this consistent annual dressing is somewhat in excess of average estate practice.

The coffee was ordinary commercial arabica, 'French Mission' type, about 30 years' old and planted at 10×10 ft. spacing without regard to contours. It had been somewhat neglected prior to purchase for experimental work in 1944. In that year it was stumped, and the first yields of the new multistem heads in 1946 were extensively sampled as a uniformity trial. The yields from the remaining 5 years of the crop cycle (1947–51 inclusive) are reported here. The annual rainfall has varied in these years from 25 to 54 in., thus departing widely from the long-term average of 37 in.

In the uniformity trial in 1946 the coefficient of variation for total fresh cherry yields of twenty-tree plots was 54·5 per cent., using the total variance, and this was reduced to 31 per cent. by eliminating the rows and columns of a 6×6 Latin Square. The data were used to orientate the blocks of the main experiment, which was laid down at the beginning of 1947. The nine blocks were arranged in three columns, separated by grassed headlands, and randomized across a shallow 20-acre drainage basin which provided a variety of slopes of between 1 and 8 per cent. The main plots each comprised sixty-nine trees, including guard rows. Each sub-plot contained two rows of ten trees, completely surrounded by a single guard row, while three extra guard rows surrounded the whole experiment in order to avoid edge-effects from drying winds. The guard-row trees were brought up on the single-stem system, while the recorded trees had three bearing heads, pruned on the multiple-stem system.

The crop was weighed as freshly picked ripe cherry; the number of pickings has varied with the rate of crop ripening in each season, from eleven in 1949 to four in 1951. Pickings were subsampled for estimation of the clean coffee content of the cherry and for quality factors; the subsamples were bulked either by blocks or by treatments in order to reduce the number of separate samples for fermentations and processing. For the statistical analysis of yield data the field weights of fresh cherry were used. In 1951 a separate sample bin was provided for each sub-plot and one-tenth of the cherry from each picking was pulped, dried, and stored as parchment coffee. At the end of the season this coffee was

hulled to give a more accurate assessment of the clean coffee yield from each sub-plot.

Yield Results

The effect of weeds on crop yields.—Table 1 gives the annual yields and 5-year totals for implement and weed-control contrasts. Unexpectedly severe and consistent reductions in yield have occurred whenever weed

TABLE 1. *Cultivation Experiment: Effects of Implements and Weeds*

(*Treatment yields as pounds of fresh cherry per acre*)

Weed control	*Season*	*Type of Implement*			*Yield totals (weed control, %)*
		Forked hand hoe	*Tractor disk*	*Tractor plough*	
Clean weeded	1947	6,099	5,826	5,331	
	1948	4,019	2,491	2,537	
	1949	6,217	5,301	5,974	
	1950	3,754	2,397	2,822	
	1951	6,125	6,044	5,957	
	Totals	26,214	22,059	22,621	70,894 (100%)
Weeds slashed (during rains)	1947	5,240	5,286	5,650	
	1948	1,604	2,041	1,833	
	1949	4,312	3,935	5,131	
	1950	1,452	1,120	1,525	
	1951	4,103	4,001	4,535	
	Totals	16,711	16,383	18,674	51,768 (73%)
Tall weeds (during rains only)	1947	5,009	5,806	5,728	
	1948	1,213	1,349	1,292	
	1949	4,001	3,936	4,089	
	1950	1,489	1,050	1,403	
	1951	2,217	2,250	2,317	
	Totals	13,929	14,391	14,829	43,149 (61%)
Totals for implements		56,854	52,833	56,124	

Least sig. diff.	P = 0·05	P = 0·01	P = 0·001
For the nine 5-yr. totals:	1,696	2,273	3,010
For the marginal totals:	2,939	3,938	5,214

competition has been permitted. Both the effects of weeds and their interaction with the effects of different implements are statistically very significant.

From Table 1 it can be seen that:

(*a*) The weed competition normally permitted during the rains caused serious reductions in crop yield, even though the coffee was kept free from weeds in the dry weather.

(*b*) About one-third of this yield loss was avoided by slashing or

mowing the weeds during the rains, followed by cultivation at the onset of dry weather.

The greatest benefit from clean weeding is shown by the hand-forked plots in which weed destruction was most thorough. Here the difference between the 5-year-total yields of clean and weedy plots reached 47 per cent. These effects are remarkable because weed competition was permitted only in wet weather, and because a similar degree of weed competition may be widely observed on commercial plantations. This is due partly to the practical difficulties of controlling the rapid weed growth which occurs at the high air temperatures experienced early in each rains; also many planters value the weeds as green manure, an opinion which Table 1 does not support.

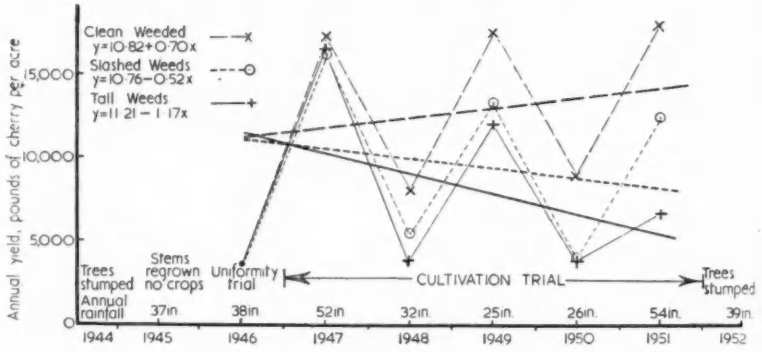

FIG. 1. Yield changes due to weed control.

The value of weeds in preventing soil erosion has been convincingly demonstrated in this experiment. Both the field observations and the laboratory measurements of soil structure, described in Part II of this paper, have shown the clean weeding to result in severe deterioration in the physical conditions of the surface soil. Sheet erosion was evident after only 3 years, on the plots clean-weeded by tractor implements. Careful hand-maintenance of narrow-based terraces at 3-ft. vertical intervals has been essential, and has, for five years, been able to prevent the run-off from reaching destructive velocity.

Fig. 1 shows that, in spite of the damage to soil structure, yields have risen steadily on the continuously clean-weeded plots. The competition of tall weeds has, however, produced a steady decrease in yield, which has been alleviated only a little by the weed-slashing treatment. In order to calculate the regressions, biennial bearing effects were first eliminated by the calculation of 2-year running averages. The regressions shown in Fig. 1 are calculated from these running averages, and their slopes are significantly different. (The assistance of P. Robinson, Statistician to E.A.A.F.R.O., in the interpretation of Fig. 1 is acknowledged with gratitude.) The differences in these regressions indicate cumulative effects of weed competition on the trees themselves. An indication of the

condition of the trees is afforded by the dying-back of some of the crop-bearing branches.

Effects of tillage treatments on die-back of branches.—Dying back of bearing branches is a normal sign of the debility produced in coffee trees by the bearing of a heavy crop. Root die-back occurs at the same time [2]. The number of such branches increases rapidly with weight of crop. Counts of about 200,000 branches made in 1950 and 1951 showed that weed competition had caused very severe increases in die-back in spite of the heavy falls in crop yield described above. The number of died-back branches per pound of cherry is shown in Table 2. The importance of reducing the competition of weeds during the rains is thus emphasized.

TABLE 2. *Dying Back of Coffee Branches*

(*Number of died-back branches per pound of cherry yield*)

	1950	*1951*
Clean weeded. . .	3·8	7·1
Weeds slashed . .	7·9	9·3
Tall weeds . . .	12·4	14·2

Yield effects of type of implement.—The highest yields have been produced consistently by clean cultivation with the forked hand-hoe, which has given results significantly better than all other treatments in each year. There have been no significant differences between the yield effects of clean weeding by disk or plough.

Where weeds were present, but partially controlled by slashing, yields were significantly better where the remaining weed growth was ploughed in, than where it was either disked or hand-forked.

Where weeds were allowed to grow tall, yields were not affected by the type of implement used to turn them in.

Implement effects, averaged over all other treatments, show that the lowest yield was obtained by disking, while a 7·6 per cent. better yield was obtained by hand-forking and 6·2 per cent. better yield was obtained with the plough. These differences were significant at the 1 per cent. and 5 per cent. levels respectively.

Yield effects of depth of tillage.—Although much visible damage to the surface roots of the coffee trees was caused by the deeper cultivations, there were no corresponding reductions in yield. Table 3 shows the 5-year total yields as a two-way table.

Depth of ploughing made no difference to the yields. Depths of disking appeared in the field to be important, since shallow disking was far less efficient in weed destruction than was deep disking. This did result in a small reduction in yield in the two dry years 1949 and 1950, but Table 2 shows no significant effect on the 5-year total yields. In the hand-forked plots depth of working did, however, have a consistent annual effect on yield. Over 5 years, the shallow-forked plots yielded some 10 per cent. less than the rest, the difference being significant at the 5 per cent. level. The single deep forking in dry weather proved as

effective as did the frequent deep workings. The effect was not, therefore, confined to efficiency in weed destruction. The plots given a single deep forking in dry weather did, however, enter the rains with a very rough cloddy tilth, and were thus provided with a very receptive surface. The importance of securing penetration of rainfall into this soil type was

TABLE 3. *Effect of Depth of Tillage on Yield*

(*5-year totals as pounds of fresh cherry per acre*)

Depth of tillage	*Type of implement*			*Total for depth*
	Forked hand hoe	*Tractor disk*	*Tractor plough*	
Shallow (2 to 3 in.) .	17,763	17,253	18,603	53,619
Shallow (plus once deep)	19,519	17,593	18,548	55,660
Deep (5 to 6 in.) . .	19,572	17,987	18,973	56,532
Least sig. diff. .	(P = 0·05) 1,696			2,939
	(P = 0·01) 2,273			3,938

shown by soil moisture studies under grass mulches [3, 4], and we have reported elsewhere substantial yield increases from the protection of the soil surface by a grass mulch applied before, rather than after, the onset of the main rains [5].

The interactions of weed control and depth of tillage showed only one minor contrast to be significant. Where weeds were slashed, the yield was least with the shallow tillage. This appeared to be due to the inability of the tractor implements, when set shallow, to kill the roots of weeds protected by the mulch of slashed weed stems.

Yield effects of subsoiling.—Exceptionally early rains in January and

TABLE 4. *Effect of Subsoiling on Yield*

(*5-year totals as pounds of fresh cherry per acre*)

	Clean weeded	*Weeds slashed*	*Tall weeds*	*Total*
s_0: no subsoiling . .	23,170	17,230	14,298	54,698
s_1: biennial subsoiling of alternate rows . .	23,347	17,203	14,368	54,918
s_2: annual subsoiling of alternate rows . .	24,377	17,335	14,483	56,195
Least sig. diff. . .	(P = 0·05) 1,696			2,939

February of 1947 prevented any effective soil-cracking by the subsoil tine, and this treatment was therefore omitted in the first year of the experiment. In the remaining 4 years subsoiling was carried out in dry conditions preceding the long rains in each year. The tine was observed to raise and to crack the soil for about 18 in. on either side of its path. The depth of penetration was between 10 and 18 in. A balanced set of

subsoiling operations was completed in the 4 years, trees in the twenty-seven s_2 plots being subsoiled twice on each side, while those in the twenty-seven s_1 plots were subsoiled once on each side. The yields are given in Table 4 for the effects of subsoiling on the 5-year cycle.

The effects did not approach significance in any one year or over-all. Considerable damage to lateral roots was observed during these operations, and the absence of any adverse effects on yield in consequence of such damage suggests that the coffee tree is rather insensitive to the cutting of surface roots. This observation is supported by the yield results from the contrasting depths of tillage. It may not apply to shaded coffee under higher rainfall conditions.

The subsoil tine was thus shown to be an inappropriate implement for coffee plantations on Kikuyu Red Loam soils. The porous nature of these soils, and the deep vertical cracks observed to occur naturally during the dry seasons, give no expectation of benefit from a subsoiling operation. Fig. 2 (Plate 5) shows the cracks occurring in soil under coffee when near to the wilting point. (The photograph was taken during the digging of the pit, and before any appreciable drying by exposure had occurred.) Subsoiling operations have thus been carried out by coffee planters through misapprehension of the physical characteristics of these sub-soils.

Yield effects of cattle manure, and interactions with tillage treatments.—Sub-plots were pooled in 1947, but were harvested separately for the

TABLE 5. *Effect of Cattle Manure on Weed Competition with Coffee*

(*4-year total yields as pounds of fresh cherry per acre*)

Weed control	*Cattle manure*	*No manure*	*Difference*	*Least sig. diff. at P = 0·05*
Clean weeded . . .	26,284	27,354	−1,070	
Weeds slashed . . .	18,645	16,946	+1,699	1,573
Tall weeds	13,656	12,951	+705	
Total	58,585	57,251	+1,334	2,723

4 years 1948–51; analysis of the eighty-one yield comparisons showed no over-all crop response to the manure. There were no significant interactions with either type of implement, depth of cultivation, or frequency of subsoiling. The manure did, however, produce a marked increase in weed growth. The increased weed growth did not significantly affect the competition by tall weeds with the coffee, but the manure significantly diminished the competition from the slashed weeds (Table 5). Reduction of yield by the slashed weeds was 38 per cent. without manure and 29 per cent. with manure. This small benefit is believed to be due to the mulching effect of the slashed weed tops. Large positive responses to grass mulching, and a lack of response to cattle manure, have already been reported from field trials adjacent to this site, and carried out in the same years [5].

Effects of Tillage on Quality of Coffee

The cherry from various treatment combinations was subsampled for separate fermentation in 1948, 1949, and 1950. Over 200 samples were thus prepared for assessment of quality. The proportion of light beans floated-off during washing and the proportion of the heavy beans which, after hulling, were retained by a Grade A (6·75 mm. round-hole) sieve, were tabulated in each year. The Grade A samples were assessed for commercial quality by the Liquoring Department of the Coffee Board of Kenya. In spite of their large yield effects the field treatments caused remarkably little difference in the quality of the coffee. Clean weeding showed a tendency to improvement in all the factors measured, but the only consistent effect to reach statistical significance was that clean weeding produced a liquor slightly better than that from the slashing of weeds. This did not alter the commercial classification of the coffee. Except in the proportion of light beans, variability was not high, and the numbers of trees and of fermentations employed were great enough to detect any effects of commercial importance. No such effects were found. This is in accordance with the results of other trials on the Coffee Research Station. Where yields are substantially increased by favourable treatments no corresponding gains in quality are observed [6].

Effects of tillage on growth-rate of trees.—At the end of the 5-year series of tillage treatments, measurements of stem-diameters of 1,080 trees revealed no significant effects of treatments on the growth of the stem.

Relation of Results to Current Practice

A summary of the main treatment yields in the terms most familiar to the industry is presented in Table 6. The results show clearly that tillage practices now current in the main coffee-producing districts in eastern Kenya require considerable alteration.

Subsoiling should be omitted except where indicated by a detailed examination of the soil profile. Weeds should be controlled far more closely. Those normally permitted are shown by these trials to cause substantial reductions in crop yield. The practice of hand forking achieves the best yields and will be shown in Part II to cause the least soil damage, but it is declining because of increasing labour costs. The plough, which gave yield results better than those of the disk, is handicapped by the presence of tough pruning trash and voluminous weed growth which causes frequent stoppages; few planters use it. The disk is widely used, but the yield results indicate that it is far from the ideal implement. There is clearly a need for a tractor-operated implement which will simulate the action of the handfork, and will leave a rough cloddy surface capable of accepting intense rainfall. Since most of the coffee has been planted without regard to contours, it is of the first importance that the tillage implement should leave no continuous furrow in

which water may achieve erosive velocity. Some tests with a rotary form of cultivator are reported in Part II.

TABLE 6. *Cultivation Experiment: Summary of Yield Results*

(*As cwt. clean coffee per acre*)

Totals, 5 annual yields, 1947–51

Type of Implement	*cwt./acre*
t_0 Forked hand hoe (*jembe*)	27·91
t_1 Tractor disk	26·06
t_2 Tractor plough	27·64

($t_0 > t_1$ at P = 0·01 ; $t_2 > t_1$ at P = 0·05)

Depth of Cultivation

d_0 Shallow only (2–3 in.)	26·43
d_1 Shallow plus once deep	27·46
d_2 Deep only (5–6 in.)	27·71

(Differences not significant)

Control of Weeds during Rains

w_0 Clean weeded	35·29
w_1 Slashed weeds	25·65
w_2 Tall weeds	20·65

($w_0 > w_1 > w_2$ at P = 0·001)

Totals, 5 annual yields, 1947–51

Subsoiling	*cwt./acre*
s_0 No subsoiling	26·81
s_1 Biennial subsoiling	27·12
s_2 Annual subsoiling	27·70

(Differences not significant)

Totals, 4 annual yields, 1948–51

Cattle Manure (sub-plots)

c_0 No manure	20·98
c_1 Annual dressing of 4 gals./tree (3½ tons per acre)	21·47

(Differences not significant)

Avoidance of cultivation.—These experiments have shown that for maximum yields in Kenya coffee plantations the soil should be kept weed-free. The soil data to be reported in Part II of this paper show that bare soil, subjected to the impact of tropical rainfall, declines substantially in its ability to accept and to transmit rainfall. The logical corollary is to protect the weed-free soil surface by a layer of mulching material. We have already reported measurements of the highly beneficial effects of a grass mulch both on crop yield and on soil structure [5]. The decay of mulching material and the vigour of tropical weed-growth render necessary some seasonal weed-cleaning operations. While rotary-cultivation implements are shown by Part II of this paper to offer promise of suitability for this purpose, there is no direct need for soil stirring, since the excellent structural conditions developed by the vigorous root activity and insect life under a grass mulch already approach the optimum. Killing of weeds by oil sprays, fortified by toxic ingredients, presents a possible solution. Initial experiments [7], following the methods tested on *Coffea arabica* in Puerto Rico [8], gave promise of successful routine control of annual weeds. Perennial stoloniferous grasses were not controlled by any sprays harmless to coffee, but these are not, at present, controlled by the tractor implements, and are eradicated by hand-digging.

Combinations of grass mulches, weed-killing sprays, and rotary tillage with a modified implement are indicated as promising lines of investigation for the improvement of coffee plantations in Kenya.

Summary

Results are presented for the first 5 years of a field study of the effects of tillage by hand hoes, and by the tractor implements which are replacing them in the coffee industry. Two rain seasons in each year gave ten effective cycles for weed control and soil structure changes.

Yields of *Coffea arabica* were heavily reduced in each year by weed competition, although this was permitted in wet weather only, all weeds being killed by cultivation at the end of each rains. The reduction in crop over 5 years amounted to 39 per cent. for tall weed growth, and 27 per cent. when weeds were slashed.

The highest yields were produced consistently by clean weeding with the forked hand hoe. Averaged over all weed conditions, the disk gave yields significantly lower than either hoe or plough.

Sub-plots were manured with cattle manure to encourage different levels of weed growth, but the manure did not increase coffee yields. The depths of tillage gave no significant yield differences and the sub-soiling tine also failed to affect yields. Large numbers of samples were tested for various quality factors, but no significant effects of tillage practices on crop classification were found.

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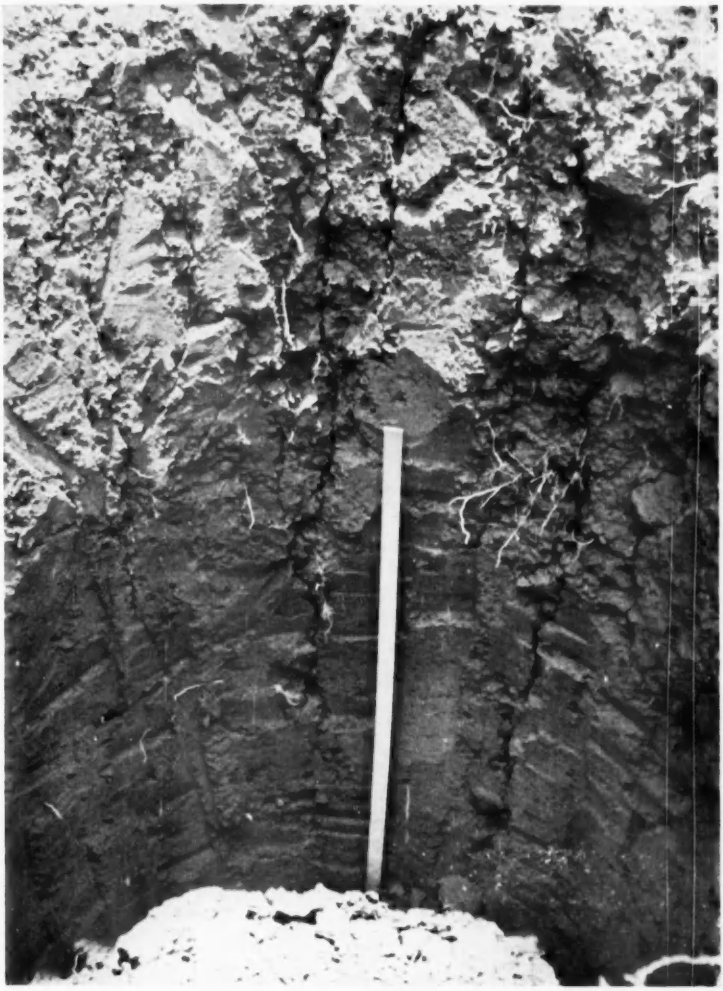

FIG. 2. Soil near wilting point under coffee trees.
A pit 2 metres deep, photographed during excavation, and before drying by exposure could take effect.
(The soil surface appears in the right-hand corner.)

THE PRODUCTION OF HUMAN FOOD IN THE UNITED KINGDOM BEFORE, DURING, AND SINCE THE WAR

JAMES WYLLIE[1]

DURING recent years there has been much discussion about the relationship between population and food supplies, sometimes on a national and sometimes on a global scale. One of the prime factors in that relationship is the acreage of land required to produce enough food for an 'average' person for a year. This study is concerned with the position in the United Kingdom during the eleven years 1939–40 to 1949–50, the average of the three years 1936–7 to 1938–9 being taken as a pre-war standard.

The basic data for the study are to be found in the official reports on the agricultural output of the U.K. [1]. Since almost complete control over the distribution of all foodstuffs was exercised by the Ministry of Food and since the periodical censuses of the Ministry of Agriculture reached a degree of completeness and accuracy not hitherto attained, the official statistics of acreages and crop yields, numbers of livestock, and quantities of crops and livestock products going into consumption, provide a sure foundation on which to compute the yearly production of human foodstuffs.

The acreage of land required to produce sufficient food for an average inhabitant for a year depends on two things: first, the amount of food necessary to maintain an average person in a healthy condition and, secondly, the yearly amount of food produced per acre of land.

Calorie Requirements per Head of Population

The first step must be to reduce all the different kinds of food—wheat, potatoes, fruit, milk, meat, &c.—to some common denominator, and it is now customary to measure the nutritive value of all foods in terms of the calorie, that is, the amount of heat required to raise 1 kilogram of water through 1° C. The justification for this method of measuring the 'food value' of any diet is that most of it is needed to supply the energy necessary for muscular and glandular action and only a comparatively small part is used for purposes of growth and repair of worn-out tissues. Nevertheless, a satisfactory health-giving diet must supply not only enough energy but also adequate quantities of protein, minerals, and vitamins. Indeed, as a measure of comparative food values the calorie is perhaps more applicable to whole mixed diets than to individual products, especially such as milk and eggs, apples and oranges, cucumbers and lettuce. In other words, a daily diet might have the required calorie content and yet be far from satisfactory because of insufficient quantities of protein or minerals or vitamins. Further, in arriving at the optimum diet some regard must be paid to the price of the calories from different sources [2, 3, 4, 5].

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[Empire Journ. of Exper. Agric., Vol. 22, No. 88, 1954]
3988.88

TABLE 1. *Estimated Value of the Gross U.K. Agricultural Output, 1949–50*

	Quantity (*1,000 tons*)	*Value* (*£ thousand*)
CROPS:		
Wheat	1,462	35,861
Barley	1,087	27,746
Oats	375	7,608
Rye	42	1,085
Mixed corn	5	101
Potatoes	5,756	68,940
Sugar-beet	3,962	19,575
Beans—stock-feed	1	22
Hay	334	2,794
Straw	585	1,202
Flax (as harvested)	90	1,819
Linseed	14	799
Hops	13	6,602
Mustard for seed	4	362
Fruit	763	30,246
Vegetables, except potatoes	2,157	70,644
Flowers and nursery stock	..	13,708
Total crops	..	289,114
LIVESTOCK PRODUCTS:		
Beef	498	84,314
Veal	26	2,157
Mutton and lamb	142	25,825
Pig meat: not for bacon	48	9,031
,, for bacon	236	57,219
Offals	94	(*a*)
Store pigs (thousands)	(116)	630
Poultry: for meat	83	20,541
,, for stock (thousands)	(4,844)	2,627
Rabbits and game	15	1,875
Milk (mill. gals.) (*b*)	(1,955)	272,443
Milk products: farm manufacture	10	2,113
Eggs	344	103,161
Wool	27	6,475
Total livestock products	..	598,411
Sundry output	..	9,651
GROSS OUTPUT	..	897,176

(*a*) Included in price of meat. (*b*) Total liquid consumption and manufacture off farms.

Note.—For crops, output is from the crop harvested in the first named year, e.g. 1949 in 1949–50; for all other products output is calculated for a June to May year, e.g. June 1949 to May 1950.

After consideration of the different requirements of men, women, and children, of workers engaged in sedentary occupations and in the 'heavy' industries and so on, the yearly requirement of food per head of population has been taken as equivalent to 1 *million calories*. This is based upon a daily intake of 3,300 calories per man and on the assumption that 1,000 head of people can be efficiently fed on the same quantity of calories as 835 men. It may be added that this standard of nutritional requirements is applicable particularly to western conditions of living.

Calorie Production per Acre of Crops and Grass

The second element in the computation of the acreage required to feed an average person for a year is the yearly output of calories from the home lands of the United Kingdom. The basic information about the annual output of the different commodities is contained in the official estimates of the value of the yearly gross U.K. agricultural output. The estimate for 1949–50 is summarized in Table 1.

In the conversion of the yearly outputs into calories, three problems arise. In the first place, not all the products can be used as human food. Amongst crops, this applies to beans (for stock-feed), hay, straw, flax, linseed, hops, mustard for seed, flowers and nursery stock. The actual, or estimated, acreages under these crops must therefore be deducted from the total acreage in order to arrive at the acreage from which the calorie production has been derived—no deduction is necessary for straw since the acreage of cereals is not affected by the value of straw sold. Amongst livestock products, wool must, of course, be excluded, while the sale of store pigs, stock pullets, and cockerels to non-agricultural users has also been excluded from the computation of calorie production, chiefly because of the great difficulty of arriving at a calorie-value estimate. Altogether, in 1949–50, 5·2 per cent. of the gross monetary output has been omitted from the calculation of calorie output.

Secondly, not all the edible crops included in the gross output were actually used for human food. For example, in 1949–50 the gross output of oats was 375,000 tons, of which 264,000 tons (70·4 per cent.) were used as human food, 102,000 tons (27·2 per cent.) sold to non-farm users (for non-farm horses, &c.), and 9,000 tons (2·4 per cent.) sold for export. In this case the acreage of oats not used for human food has been calculated from the average yield per acre and deducted from the total average of oats. This procedure has been followed each year for both oats and barley. No deduction has been made from the wheat acreage since only between 1 and 2 per cent. of the gross output was not used as human food. In the pre-war period, however, 13·2 per cent. of the wheat was not so used and an appropriate reduction has been made in the total acreage. No adjustments in the acreages have been thought necessary for any of the other food crops.

The third and much the most difficult problem is to determine the calorie value (per lb. or other unit) of each of the edible products given in Table 1. The calorie values per lb. finally decided upon after much cogitation are given in Table 2.

With wheat, oats, potatoes, sugar beet, milk, and eggs there is fairly

general agreement about the calorie values, and it is important to remember that, on the average, the calories derived from these six products comprise about 76 per cent. of the total calorie output as here computed —ranging from 68 per cent. in 1939–40 to 81 per cent. in 1943–4.

With the other products—barley, fruit, vegetables (other than potatoes),

TABLE 2. *Schedule of Calorie Values per Pound of Output*

Product	*Extraction rate*	*Calorie value per lb.*
Wheat, pre-war	70	1,095
1939–40	73	1,142
1940–1	73	1,142
1941–2	85	1,330
1942–3	85	1,330
1943–4	85	1,330
1944–5	81	1,268
1945–6	82	1,283
1946–7	87	1,362
1947–8	85	1,330
1948–9	85	1,330
1949–50	85	1,330
Barley	..	720
Oats	..	1,080
Rye	..	1,200
Mixed corn	..	1,100
Potatoes	..	350
Sugar-beet	..	250
Fruit	..	150
Vegetables (other than potatoes)	..	75
Milk	..	300
Eggs	..	630
Beef	..	1,250
Veal	..	600
Mutton and lamb	..	1,400
Pig meat	..	1,600
Offals—all	..	700
Poultry meat	..	440
Rabbits and game	..	460

and all kinds of meat—the calorie values are necessarily somewhat arbitrary, but an error of even 10 per cent. in the total computed calories from these sources would be equivalent to an error of only 2½ per cent. in the total calorie production from all sources: it should be kept in mind that errors in the conversion of individual commodities into calories will tend to cancel one another out.

An example of the procedure used in arriving at the acreage required to feed an average person for a year is given in Table 3.

Changes in Sources of Calorie Production

During this period—1936–7 to 1938–9 and 1939–40 to 1949–50—one important result of the war-time regulations for both crops and livestock was a very marked change in the pattern of agricultural output in the

TABLE 3. *Calorie Output in U.K., 1949–50*

Product	*Acreage*	*Yield per acre*	*Sold for human food*	*Total calorie value*	*Per-centage*
	1,000's	*cwt.*	*1,000 tons**	*millions*	
Wheat	1,963	22·5	1,462	4,355,590	18·2
Barley	2,060	20·7	954 (1,087)	1,538,612	6·4
Oats	3,252	18·4	264 (375)	638,669	2·7
Rye	65	16·8	42	112,896	0·5
Mixed corn	680	19·0	5	12,320	0·1
	8,020	..	2,727	6,658,087	27·9
		tons			
Potatoes	1,308	6·9	5,756	4,512,704	18·9
Sugar-beet	421	9·5	3,962	2,218,720	9·3
	1,729	..	9,718	6,731,424	28·2
Fruit	324	..	763	256,368	1·1
Vegetables	533	..	2,157	362,376	1·5
	857	..	2,920	618,744	2·6
TOTAL CROPS	..	..	..	14,008,255	58·7
Milk (mill. gals.)	..	..	2,011	6,213,990	26·1
Eggs	..	..	344	485,453	2·0
	..	..	..	6,699,443	28·1
Beef	..	..	498	1,394,400	5·8
Veal	..	..	26	34,944	0·2
Mutton and lamb	..	..	142	445,312	1·9
Pig meat	..	..	284	1,017,856	4·3
Offal—all	..	..	94	147,392	0·6
Poultry meat	..	..	83	81,805	0·3
Rabbits and game	..	..	15	15,456	0·1
	..	..	1,142	3,137,165	13·2
TOTAL LIVESTOCK	..	..	..	9,836,608	41·3
GRAND TOTAL	..	..	..	23,844,863	100·0

* Figures in parentheses represent total farm sales.

Total acreage—crops and grass		31,056,000
Less		
Barley, Oats not for human food	128,500 + 120,500	
Beans—stock-feed	1,250	
Hay	267,250	
Flax	46,000	
Linseed	22,500	
Hops	22,000	
Mustard seed	15,000	
Flowers and nursery stock	20,000	
		643,000
Net acreage		30,413,000

Calories per acre: 784,035. Acreage per person: 1·28. Persons fed per 100 acres: 78·4.

U.K. Not only were there large variations in the acreage devoted to the different crops but also there were marked changes in the numbers of the different classes of livestock. Further, seasonal conditions during growth and at harvest resulted in considerable fluctuations in the average annual yields per acre of crops, while feeding and other difficulties brought about large variations in the annual average yields from dairy cows and laying hens. Hence, even in a period when strong efforts were made to control the yearly output of foodstuffs, the actual yearly output showed very large fluctuations. (See Table 4, below.)

Crops.—The overriding change on the cropping side was an increase in the area of tillage land from 8·9 million acres in 1936–9 to 14·6 million acres in 1944–5, followed by a decline to 12·7 million acres in 1949–50. At the same time, the area under permanent grass fell from 18·7 to only 11·7 million acres and then rose to 12·7 million acres. The cereal acreage increased from 5,305,000 in 1939 to a maximum of 9,560,000 in 1943, that is, by 80 per cent., and then declined to 8,020,000 in 1949. Since about 66 per cent. of the computed calories from cereals came from wheat, the increase in the area under wheat from 1,766,000 acres in 1939 to no less than 3,464,000 acres in 1943, followed by a fall to only 1,963,000 acres in 1949, is of particular importance.

The area under potatoes was 704,000 acres in 1939, increased to 1,548,000 acres in 1948, and then fell to 1,308,000 acres in 1949; while the acreage of sugar-beet was 344,000 in 1939, 431,000 in 1944, 395,000 in 1947, and 421,000 in 1949.

As regards yields per acre, the position can be summarized thus:

	Highest yield per acre	*Year*	*Lowest yield per acre*	*Year*
Wheat	22·5 cwt.	1949	15·4 cwt.	1947
Barley	20·7 ,,	1949	15·5 ,,	1941
Potatoes . . .	7·7 tons	1940	5·8 tons	1947
Sugar-beet . . .	10·5 ,,	1946 / 1948	7·6 ,,	1947

The year 1947 stands out as one of uniformly poor yields per acre while in 1949 the average yields were good to very good. It is clear that even with the same acreages the total crop outputs would still fluctuate considerably from year to year.

Livestock.—The number of dairy cattle increased steadily from 3·8 million in pre-war years to 4·6 million in 1949–50; the number of sheep declined from 26·4 million to only 20·1 million in 1944–5 and to 19·5 million in 1949–50; the number of pigs fell from 4·4 million in 1939–41 to only 1·6 million in 1947–8; and the number of poultry was 74·4 million in 1939–40, 50·7 million in 1943–4, and 95·5 million in 1949–50.

The average gross yield per cow was estimated at 542 gallons per annum in pre-war years; it fell to only 459 gallons in 1941–2 and then rose steadily to 581 gallons in 1949–50. The average annual yield of eggs per hen was estimated at 148 in pre-war years, it declined to only 111 in 1943–4, and then it increased to 131 in 1949–50.

Total output.—The extent of the yearly variations in the main sources of calorie production during this period is clearly shown in Table 4.

It will be seen that the total output of cereals for human food increased rapidly from 1,379 thousand tons in pre-war years to 4,292 thousand tons in 1943–4 (that is, by over 200 per cent.), and then fell steadily to 2,727 thousand tons in 1949–50; the output of potatoes rose from 3,191 thousand tons in 1936–9 to 6,094 thousand tons in 1943 and to a maximum of 6,623 thousand tons in 1946–7, the output in 1949–50 being 5,756 thousand tons; sugar-beet also reached the maximum output in 1946–7 at 4,522 thousand tons compared with only 2,741 thousand tons in 1936–9.

TABLE 4. *Principal Sources of Calorie Production in the U.K.*

Year	*Cereals*	*Potatoes*	*Sugar-beet*	*Fruit and vegetables*	*Milk*	*Eggs*	*Meat*
	1,000 tons	*1,000 tons*	*1,000 tons*	*1,000 tons*	*mill. gals.*	*1,000 tons*	*1,000 tons*
1936–9	1,379	3,191	2,741	2,415	1,563	304	1,413
1939–40	1,426	3,224	3,529	2,813	1,550	308	1,397
1940–1	1,771	3,766	3,176	2,695	1,446	291	1,359
1941–2	2,582	4,333	3,226	2,728	1,417	218	917
1942–3	3,604	4,934	3,924	3,478	1,522	165	961
1943–4	4,292	6,094	3,760	3,288	1,580	160	919
1944–5	3,599	6,061	3,267	3,488	1,594	169	943
1945–6	2,927	6,309	3,886	3,379	1,654	195	995
1946–7	2,612	6,623	4,522	3,381	1,665	198	958
1947–8	2,322	5,225	2,960	3,346	1,704	223	845
1948–9	2,999	6,263	4,319	3,369	1,909	279	983
1949–50	2,727	5,756	3,962	2,920	2,011	344	1,142

The output of milk fell from 1,563 million gallons in pre-war years to 1,417 million gallons in 1941–2, largely owing to the heavy reduction in the supplies of purchased concentrates before farmers had time to adjust their cropping programmes to meet the requirements of the cows, and then increased gradually to 2,011 million gallons in 1949–50; the output of eggs declined from 304 thousand tons to only 160 thousand tons in 1943–4 and then rose steadily to 344 thousand tons in 1949–50; while the total output of all kinds of meat fell from 1,413 thousand tons in 1936–9 to only 919 thousand tons in 1943–4 and then increased rather erratically to 1,142 thousand tons in 1949–50.

It should be noticed that with all products except meat the output in 1949–50 was substantially higher than in 1936–9, but the supplies of meat were still 271 thousand tons below the pre-war level.

Percentage composition of calorie output.—The changes in the composition of the yearly output of human food, in terms of calories, are summarized in Table 5.

The outstanding feature of this table is the variation in the relative importance of crops and livestock as a source of human food. In 1939–40, crops contributed about 47 per cent. and livestock about 53 per cent.

of the total calorie production, compared with 71 and 29 per cent. respectively in 1943–4. By 1949–50, however, the contribution from livestock had risen to 41 per cent. and that from crops had fallen to 59 per cent.

The percentage of calories from cereals ranged from as low as 18 in 1939–40 to as high as 42 in 1943–4, whereas that from potatoes and sugar-beet was never less than 26 (1939–40) or more than 34 per cent. (1946–7). The contribution by fruit and vegetables (other than potatoes) averaged only about 3 per cent.—from 2·5 in 1943–4 to 3·6 per cent. in 1947–8.

TABLE 5. *Percentage Composition of Calorie Output in the U.K.*

	Crops				*Livestock*			
Year	*Cereals*	*Potatoes and sugar-beet*	*Fruit and vegetables*	*Total*	*Milk and eggs*	*Meat*	*Total*	*Total*
1936–9	17·6	24·2	2·9	44·7	31·5	23·8	55·3	100·0
1939–40	17·7	26·0	3·5	47·2	30·2	22·6	52·8	100·0
1940–1	21·6	26·5	3·1	51·2	27·4	21·4	48·8	100·0
1941–2	33·4	26·9	2·6	62·9	24·3	12·8	37·1	100·0
1942–3	38·3	26·2	3·1	67·6	21·2	11·2	32·4	100·0
1943–4	42·5	26·2	2·5	71·2	19·4	9·4	28·8	100·0
1944–5	37·2	27·6	2·9	67·7	21·7	10·6	32·3	100·0
1945–6	30·3	31·4	2·9	64·6	23·7	11·7	35·4	100·0
1946–7	28·3	33·8	3·0	65·1	23·8	11·1	34·9	100·0
1947–8	27·3	29·4	3·6	60·3	28·5	11·2	39·7	100·0
1948–9	30·2	30·2	2·8	63·2	26·0	10·8	36·8	100·0
1949–50	27·9	28·2	2·6	58·7	28·1	13·2	41·3	100·0

In 1939–40 no less than 30·2 per cent. of the calorie production was derived from milk and eggs compared with only 19·4 per cent. in 1943–4. Lastly, and in some ways most important of all, only about 9½ per cent. of the computed calorie output in 1943–4 came from meat of all kinds, against 22½ per cent. in 1939–40 and about 13 per cent. in 1949–50.

Acreage Required to Feed One Person, and Total Number of Persons Fed

Table 6 summarizes the answers to the two vitally important questions: first, what acreage of land is required to feed an 'average' person for a year; and, secondly, what is the total number of persons fed on the produce of U.K. land, assuming a yearly consumption of 1 million calories per person.

Yearly acreage per person.—Table 6 shows that in pre-war years 1·85 acres were required to feed one person; it was only slightly less in the first two years of the war, but in 1943–4 only 1·15 acres were required. During the rest of the period, the area required remained fairly constant at around 1·3 acres, except in 1947–8 when, largely owing to the poor crop yields, it was 1·54 acres.

These figures may be compared with other estimates which have been made. In 1923 Middleton estimated that in 1909–13 it required 3 acres of cultivated land to feed one person in the U.K. for a year [6]; in 1926 Hall gave a figure of 2 to 2½ acres [7]; and in 1942 Sir John Russell a figure of 1·7 acres [8].

Total number of persons fed.—Table 6 also shows that in pre-war years the land in the U.K. provided enough food for a population of about 16½ millions; in the first two years of the war, this figure rose to about 17¾ millions, it moved rapidly upwards to a maximum of about 26¼ millions in 1943–4 and then settled around 23 millions, except in 1947–8

TABLE 6. *Calorie Production per Acre, and Number of Persons Fed in the U.K. from Home Production*

Year	*Calories produced per acre*	*Acreage to feed one person*	*Persons fed per 100 acres*	*Total number of persons fed (1,000's)*
1936–9	540,617	1·85	54·1	16,687
1939–40	560,760	1·78	56·1	17,324
1940–1	582,523	1·72	58·3	17,828
1941–2	633,274	1·58	63·3	19,321
1942–3	763,091	1·31	76·3	23,167
1943–4	867,325	1·15	86·7	26,285
1944–5	788,177	1·27	78·8	23,849
1945–6	754,696	1·33	75·5	22,712
1946–7	754,107	1·33	75·4	22,826
1947–8	646,783	1·54	64·7	19,579
1948–9	796,270	1·26	79·6	24,224
1949–50	784,035	1·28	78·4	23,845

when it was only about 19½ millions. Taking the six years 1944–5 to 1949–50 as a long enough period to even out seasonal fluctuations, it would appear that on the average of these years 1·33 acres were sufficient to feed an average person for a year, equivalent to a population of about 22¾ millions, against only about 16½ millions in 1936–9—an increase of fully 37 per cent.

In so far as a fairly high proportion of calories from animal products is associated with high 'quality' in the diet, Table 5 shows that the quality deteriorated during the war years and then improved appreciably up to 1949–50. It is, of course, clear that under war conditions the home lands could be made to support much larger numbers than those given in Table 6, not only by increased dependence on food crops such as wheat, oats, potatoes, and sugar-beet, but also by lowering the standard of nutrition below 1 million calories per person per annum. It is also clear that provision must always be made against the probability of an abnormally low production as a result of very unfavourable seasonal conditions such as were in fact experienced in 1947–8.

It should perhaps be added that in the early years of the war some part of the calorie output was due to 'capital realization'. For example, the rapid decline in the numbers of sheep, pigs, and poultry meant that

a proportion of the breeding stocks was slaughtered and made available for human food, while in the case of the better-class permanent pastures it became possible to utilize the stored-up fertility. It seems likely, however, that the total effect of this capital realization on the yearly calorie output would be comparatively small. Towards the end of the period under review, the gradual increase in the numbers of sheep, pigs, and poultry would have a very slight effect in the opposite direction.

Index of Calorie Production, and Price per Million Calories

As already mentioned, in the determination of the optimum diet some regard must be paid to its price as well as to its calorie content and

TABLE 7. *Index of Calorie Production, and Price per Million Calories*

	Index of calorie production	*Price per 1,000,000 calories*	*Price per 1,000,000 calories*				
			Wheat	*Potatoes and sugar-beet*	*Meat (all kinds)*	*Milk*	*Eggs*
		shillings	*shillings*	*shillings*	*shillings*	*shillings*	*shillings*
1936–9	100·0	321	115	98	481	332	1,457
1939–40	103·7	374	123	100	558	383	2,007
1940–1	107·7	474	..	..	..	..	..
1941–2	117·1	474	..	..	..	..	..
1942–3	141·2	446	..	..	..	..	..
1943–4	160·5	416	127	196	871	645	3,123
1944–5	145·8	452	139	202	867	667	3,144
1945–6	139·6	497	..	..	..	..	..
1946–7	139·5	525	..	..	..	..	..
1947–8	119·6	656	..	..	..	..	..
1948–9	147·3	627	163	266	1,288	822	4,008
1949–50	145·0	709	165	263	1,345	884	4,250

Equivalent price	*per gal.*	*per doz.*
	s. d.	*s. d.*
1936–9 .	1 0½	1 4½
1939–40 .	1 2½	1 11½
1943–4 .	1 11½	3 0
1944–5 .	2 0½	3 0
1948–9 .	2 6½	3 9½
1949–50 .	2 9	4 0

quality, and Table 7 gives the average yearly price per million calories and also the price per million calories derived from various sources. It also shows the index of calorie production for each year as compared with the pre-war years.

Calorie production per acre increased only slightly during the first two years of the war; it then increased rapidly to a maximum of 60·5 per cent. above pre-war, after which it remained fairly steady at about 40 per cent. above 1936–9, except in 1947–8, when it was only about 20 per cent. above the pre-war level.

The cost per million calories was about £16 in pre-war years, rose to about £24 in 1941–2, fell to about £21 in 1943–4, and then rose steadily to about £35 in 1949–50. The cost per million calories for different food

products confirms what is generally accepted: that crops are a much more economical source of calories than livestock products. Even so, it will come as a surprise to many that in 1949–50, for example, a million calories derived from wheat cost only about £8, or from potatoes and sugar-beet about £13, compared with about £67 from meat, £44 from milk, and no less than £212 from eggs. These are, of course, the prices received by the producer and should not be confused with those paid by the consumer. As already pointed out, the justification for the inclusion of animal products in the diet is that they have a profound effect on its quality and palatability.

Other Aspects of the Problem

So far, this paper has been solely concerned with 'agricultural holdings' over 1 acre in size (or ¼ acre in Northern Ireland) and with the acreages of 'crops and grass', but this definition of the problem does not take account of all its aspects and a brief reference must now be made to these broader aspects.

Non-farm Production.—In a complete appraisal of home production it is necessary to include the output of fruit, potatoes, and other vegetables from gardens and allotments, of pigs, poultry, and eggs from 'domestic' pig and poultry keepers, and of any other land outside the official definition of 'agricultural holdings'. According to official statistics, the average yearly production of pig meat from such sources was about 28,000 tons and of eggs about 121,000 tons. These products not only made a welcome addition to the quality of the diet but also enabled about 271,000 additional persons to be fed each year, compared with about 186,000 persons in pre-war years. In the smaller country towns and in the villages the contribution of 'domestic' fruit, potatoes, and other vegetables to the diet must be quite appreciable, but no official statistics are available under this heading for the country as a whole.

Output from rough grazings.—In the above computations of the acreage required to feed an average person for a year, no allowance has been made for the 17 million acres of rough grazings on hills and moorlands. The chief products from this land are store lambs, cast ewes, and wool, as well as a limited number of store cattle. But since the calories derived from mutton and lamb comprise only between 2 and 3 per cent. of the total calorie production and since a considerable proportion of the mutton and lamb has its origin on the 'crops and grass' and not on the rough grazings, it is probably fair to say that not more than 1 per cent. of the total calorie output can be attributed to the rough grazings. In other words, the omission of rough grazings has no appreciable effect on the acreage required per person.

Imports of feeding-stuffs, seeds, and livestock.—In a strict accounting of the calorie output from the home lands allowance would have to be made for the contribution from imported livestock, feeding-stuffs, and seeds. For example, if store cattle are imported from Eire and fattened in the U.K. it is clear that only the increase in the calorie value which takes place in the U.K. can properly be credited to U.K. production. It is also clear that in the absence of imported feeding-stuffs and seeds either more

land would have to be devoted to producing these commodities or there would have to be some reduction in the output of milk, eggs, and meat.

It is, however, easy to overestimate the part which these imports play in the total calorie production of the U.K. For one thing, it is unlikely that the edible value of the store cattle imported during this period represented as much as 1 per cent. of the total calorie output; for another, the crucial question is not what size of population could be supported on the home lands without the help of imports of any kind, but to what extent is it desirable in the national interests to supplement purely home food production by imports of livestock, feeding-stuffs, and seeds? It is perhaps sufficient to say here that consideration of these imports is not likely to invalidate any of the conclusions that have already been suggested by this study.

TABLE 8. *Indexes of Workers Engaged in Agriculture, Total Calorie Production, and Calorie Production per Man*

Year	*Man-equivalents engaged** (*Williams*)	*Total calorie production* (*Table 7*)	*Calorie production per man.*
1936–9	100	100·0	100
1939–40	99	103·7	105
1940–1	101	107·7	107
1941–2	103	117·1	114
1942–3	107	141·2	132
1943–4	108	160·5	149
1944–5	109	145·8	134
1945–6	107	139·6	130
1946–7	108	139·5	129
1947–8	108	119·6	111
1948–9	108	147·3	136
1949–50	105	145·0	138

* Includes an appropriate allowance for work done by farmers, their wives, and other unpaid family workers.

Calorie production per man.—It may be asked: what changes in the calorie production per man engaged in agriculture have there been during the period under review? The yearly total calorie production has been computed, and the most authoritative recent computation of the number of 'man-equivalents' engaged in agriculture during this period is that made by H. T. Williams [9]. The relevant data are brought together in Table 8.

It would appear that the calorie production per man engaged in agriculture increased to a maximum of 49 per cent. above the pre-war level in 1943–4, fell to as low as 11 per cent. in 1947–8, and then rose to about 37 per cent. above pre-war in the last two years. It would, however, be wrong to conclude that this increased production per man was due entirely, or even mainly, to the greater physical efforts of farm workers. For not only were the workers much better equipped with machinery of all kinds than they were in pre-war days, but also much larger quantities of fertilizers and lime were used, while the general standard of farm

management was appreciably higher. Further, a fair comparison of the production per man in the pre-war and in the war and post-war years would have to take into account the number of men who were employed in the construction and repair of the additional machinery that was used. In short, although the data given in Table 8 are interesting as far as they go they do not tell the whole story and care must be taken not to draw the wrong conclusions from them.

Discussion

This study has shown that under the strain of war and post-war conditions the number of people fed on the produce of the home lands of the United Kingdom was substantially greater than in pre-war years; it has also shown that even under such conditions the number fluctuated considerably from year to year. It may now be of interest to discuss very briefly the chief factors that were responsible for that increase in production as well as for the fluctuations therein. A fuller discussion, along with detailed statistics, is given in [10].

There is little doubt that the factor of overriding importance was the acreage of tillage land. This increased from 8·9 million acres in 1936–9 to a maximum of 14·6 million acres in 1944–5 and then declined to 12·7 million acres in 1949–50. On the other hand, the acreage under permanent grass fell from 18·7 million in 1936–9 to only 11·7 million in 1944–5 and then rose to 12·7 million in 1949–50. Of the tillage land crops, by far the most important contributors to calorie production were wheat, potatoes, and sugar-beet, and it is not without significance that in 1943–4—the year of highest calorie output—the acreage of wheat was at a maximum of 3,464,000, compared with 1,856,000 in 1936–9 and 1,963,000 in 1949–50.

It is perhaps not sufficiently realized that 1 million calories can be obtained from:

0·41 acre of a 20-cwt. crop of wheat, or
0·18 acre of a 7-ton crop of potatoes, or
0·18 acre of a 10-ton crop of sugar-beet.

On the other hand, the production of 1 million calories in the form of milk needs about 1·6 acres of land yielding at the rate of 200 gallons per acre, which is much above the average rate of production.

Nevertheless, as already shown, total calorie production depends not only upon the acreage grown but also upon the average yields per acre. For example, in 1947–8 the effect of the comparatively low yields per acre was to reduce the calorie production per acre of cereals, potatoes, and sugar-beet by nearly 20 per cent. compared with 1946–7. High average yields per acre are, of course, largely dependent on the seasonal conditions during growth and at harvest, but they are also largely influenced by the efficiency of the farm management, particularly in respect of the manures applied, the varieties planted, and the cultural methods.

It cannot be too strongly emphasized that, in so far as the official agricultural policy is based upon the production of the maximum quantity of human food from the home lands, the crops of vital importance

are wheat, potatoes, and sugar-beet. The surest way of bringing about a marked decline in human food production would be to make the growing of these crops relatively unprofitable, that is, less profitable than the production of milk and meat.

However, the variations in crop acreages and numbers of livestock represent only one of many changes in the pattern of agricultural production during the years under review.

In one important respect, the change has been against home food production. Imports of animal feeding-stuffs were, of course, severely restricted and as early as 1940–1 the quantity imported was only 59 per cent. of pre-war years. In 1943–4 it was only 18 per cent. and even by 1949–50 it was no more than 46 per cent. [9]. There is little doubt that if the imports of animal feeding-stuffs could have been maintained on the pre-war scale the production of milk, eggs, and meat would have been much greater than it was.

In other respects, however, the changes were all in favour of increased production of human food. First—and this is a point often overlooked—the reduction in the number of farm horses from 724,170 in 1939 to only 454,439 in 1949 meant that somewhere about a million acres of land were set free for the production of food crops or of milk, eggs, and meat. Instead of the horse there is now the internal combustion engine with its large family of machinery, and the essential difference between the horse and the internal combustion engine in this context is that whereas the former is produced on, and fed off, the land, the latter makes no demand at all upon the land. Perhaps the clearest indication of the growth of what is now called farm mechanization is that the quantity of fuel used by machinery on the farm in 1949–50 was fully four times as much as it was in 1936–9 [9]. In so far as motive power is concerned, British agriculture is certainly much less self-supporting than it was in pre-war days.

There is general agreement that not only has mechanization made possible the increased acreage of tillage land, in spite of the large reduction in the number of horses and without any increase in the number of farm workers, but also it has given the farmer greater control of his tillage and harvesting operations and this has tended to raise the yields per acre.

The third big change in favour of increased production has been the much greater use of both fertilizers and lime. It has been estimated [9] that applications of nitrogen (as sulphate of ammonia, &c.) were 275 per cent. heavier in 1949–50 than in 1936–9, the corresponding figure for phosphoric acid (as superphosphate, &c.) being 170 per cent. Applications of potash (as muriate of potash, &c.) declined by 37 per cent. in 1940–1 and then rose to 212 per cent. above the pre-war quantity in 1949–50. The quantity of lime (CaO) applied in 1939–40 was 23 per cent. less than in 1936–9 but in 1949–50 it was 142 per cent. more.

As regards the efficiency of farm management, no precise measurements are available, but the general impression is that under the impetus of the county war agricultural executive committees there was an appreciable improvement throughout the war and post-war years.

Reference has already been made to the changes in the composition

of the calorie output during this period, and it is clear that the same total output can be obtained from very different combinations of food crops and livestock products. For example, the total calorie production in 1944–5 and 1949–50 was practically the same, but whereas in 1944–5 68 per cent. of the total calories was derived from food crops and only 32 per cent. from animal products, the corresponding figures for 1949–50 were 59 and 41 per cent. Judged by western standards of nutrition, the 'quality' of the diet provided from the homelands in 1949–50 was definitely superior to that of 1944–5, but, on the other hand, the cost of 1 million calories in 1949–50 was about £35 as against only £23 in 1944–5.

Summary

On the basis of an allowance of 1 million calories per average person per annum, it is shown that in 1939–40 the acreage of crops and grass required to produce this quantity of food in the U.K. was 1·78, in 1943–4 it was only 1·15, it increased to 1·54 in 1947–8, and it was about 1·27 in 1948–9 and 1949–50.

The percentage composition of the yearly calorie production varied considerably. Food crops contributed 47 per cent. in 1939–40, rising to 71 in 1943–4 and falling to 59 per cent. in 1949–50, while the contribution of cereals ranged from 18 per cent. in 1939–40 to 42 in 1943–4 and 28 per cent. in 1949–50. Meat of all kinds contributed only about 9 per cent. in 1943–4 against 23 in 1939–40 and 13 per cent. in 1949–50.

The yearly variations in the calorie output were due partly to the variations in the acreages of crops and numbers of livestock, and partly to variations in the average yields per acre of crops and per head of livestock.

The total number of persons fed from U.K. crops and grass was about 17·3 millions in 1939–40, 26·3 millions in 1943–4, 19·6 millions in 1947–8, and 23·8 millions in 1949–50, compared with about 16·7 millions in pre-war years.

The cost per million calories was substantially higher in animal than in crop products.

It is suggested that the optimum combination of crops and livestock for food production purposes must have regard not only to the quantity of calories produced but also to the quality of the diet and its price.

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(*Received 16 August 1954*)

EFFECT OF CROSSING EGYPTIAN SHEEP ON GROWTH AND DEVELOPMENT OF LAMBS

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CROSS-BREEDING has been used very extensively for mutton and lamb production in many countries [1]. Most reports have shown that cross-bred lambs excel their pure-bred parents in many of their economic characters such as body weight, growth rate, and daily gain. Comparatively little experimental work has been done, however, on crossing indigenous breeds of sheep in tropical and subtropical countries.

This experiment was planned to study the effect of crossing two breeds of Egyptian sheep, i.e. Ossimi and Rahmani, on the weight, body measurements, and daily gain of cross-bred lambs, and to compare the pure-bred lambs with the cross-bred ones in these respects. The Ossimi and the Rahmani breeds were chosen because they are the main breeds raised in the country which are used for mutton production.

Experimental procedure and method of analysis.—This experiment was carried out for 3 years (1951–4) in the Animal Breeding Department, Faculty of Agriculture, Giza. During the mating season (May-June), the two flocks of Ossimi and Rahmani sheep were divided at random into four groups of ewes. Rahmani males were mated to one group of Rahmani ewes and to another group of Ossimi, in order to produce pure-bred and cross-bred lambs; Ossimi rams were similarly mated to two groups of Ossimi and Rahmani ewes. Thus the following four groups of lambs were obtained: pure Ossimi, pure Rahmani, cross-bred lambs from Ossimi females with Rahmani males, and cross-bred lambs from Ossimi males with Rahmani females. The numbers of lambs included in the experiment were 110, 83, 81, and 53 from the respective groups.

Lambs were weighed and measured within 24 hours of birth, then every 2 weeks till they were weaned at 4 months of age, and then every month till they reached 8 months. Weights were recorded to the nearest 0·1 kg., while measurements were taken to the nearest cm. Measurements used for studying the development of the lambs were heart girth, body length, and height at shoulder. Systems of feeding and management were more or less the same during the 3 years of the experiment.

In order to normalize the data, the observations were transferred into their corresponding logarithms, and the arithmetic means of the logs were obtained and transferred back into their antilogs. Thus the antilogs were in fact the geometric mean of the actual weights and measurements. Means, standard errors, and coefficients of variability were calculated, and tests of significance between mean logs were carried out at the 5 per cent. level of probability [2].

Results.—Analysis of the data indicated that there were no significant

[Empire Journ. of Exper. Agric., Vol. 22, No. 88, 1954]

differences between different years in the weights and measurements of lambs born during the 3 years of the experiment, and the data were therefore pooled. Means of weights and measurements for different groups of lambs, as well as their standard errors, are shown in Table 1. Only lambs dropped during the first two seasons (1951–2 and 1952–3) were used for studying weights and measurements at 8 months of age.

TABLE 1. *Average Weights (kg.) and Measurements (cm.) of Pure-bred and Cross-bred Lambs*

	Ossimi	*Rahmani*	*Rahmani F.* × *Ossimi M.*	*Ossimi F.* × *Rahmani M.*
NO. OF LAMBS AT BIRTH	110	83	53	81
Birth weight	3·0±0·106	3·5±0·122	3·6±0·112	3·2±0·094
Heart girth	31·1±0·403	32·4±0·454	32·9±0·133	32·3±0·423
Body length	28·0±0·388	30·1±0·451	30·7±0·419	30·0±0·264
Height at shoulder	35·6±0·342	36·7±0·424	36·9±0·450	36·1±0·206
NO. OF LAMBS AT 4 MO.	92	66	59	72
Body weight	17·8±0·716	18·9±0·931	22·2±1·001	19·0±0·938
Heart girth	53·5±0·743	54·2±0·827	60·7±0·799	58·5±1·017
Body length	49·3±0·527	52·5±0·774	56·0±0·784	54·7±0·975
Height at shoulder	54·1±0·611	55·5±0·745	58·9±0·728	57·9±0·740
NO. OF LAMBS AT 8 MO.	65	46	25	29
Body weight	22·7±1·031	22·3±1·244	28·0±1·822	29·1±1·515
Heart girth	56·6±0·802	56·1±1·012	61·1±1·059	61·6±1·135
Body length	54·4±0·754	55·9±0·757	60·3±1·257	59·5±1·218
Height at shoulder	58·3±0·640	58·4±0·683	62·2±1·121	62·5±0·890

Table 1 shows that the cross-bred lambs were generally superior to the Ossimi and Rahmani lambs in body weight and dimensions at the three stages of life studied. When the cross-bred lambs are compared with the individual breeds, the cross-bred excelled the Ossimi lambs in weight and measurements at all three stages, and differences between the two groups were statistically significant. On the other hand, there were no significant differences between the Rahmani lambs and the cross-bred ones at birth, whereas the differences between the two groups of lambs were significant at 4 and 8 months of age.

It was also noted that the cross-bred lambs produced by Rahmani ewes were heavier and bigger at birth and at weaning age than the group produced by Ossimi ewes. Differences between the two cross-bred groups were statistically significant except for heart girth at birth and body length at weaning age. However, at 8 months of age there were no significant differences between the cross-bred groups.

The coefficients of variability of weight at birth and at 8 months of age were smaller for cross-bred lambs than for either Rahmani and Ossimi ones, but at weaning age they were more or less the same, being 18·0, 19·6, and 20·5 per cent. respectively for Ossimi, Rahmani, and cross-bred lambs. The coefficients of variability of body measurements showed

the same trend, although the values obtained were smaller than those found for weight.

Table 2 presents the daily gain in body weight and dimensions for pure-bred and cross-bred lambs before weaning age.

It is evident that the cross-bred lambs were superior to the Ossimi and Rahmani lambs in their daily gain, and differences between the two groups were statistically significant in both weight and measurements. Cross-bred lambs produced by Rahmani females gained more weight per day than did the other cross-bred group, the difference between the

TABLE 2. *Daily Gain in Body Weight and Measurements for Lambs before Weaning*

	Ossimi	*Rahmani*	*Rahmani F.* × *Ossimi M.*	*Ossimi F.* × *Rahmani M.*
Body weight . . .	0·126	0·127	0·156	0·135
Heart girth . . .	0·181	0·185	0·206	0·201
Body length . . .	0·185	0·182	0·214	0·219
Height at shoulder . .	0·150	0·156	0·177	0·181

two groups being significant. However, there were no significant differences between the two cross-bred groups in the daily gain of body measurements.

Discussion

Results obtained in this experiment confirm the work reported by other investigators, using different breeds of sheep, who found that cross-bred lambs are superior in many respects to their pure-bred mates. Our analysis indicated that the cross-bred lambs exceeded the Ossimi and the Rahmani lambs in body weight by 5, 12, and 27 per cent. at birth, 4 months, and 8 months of age respectively. Differences in heart girth, body length, and height at shoulder were of similar magnitude. In other words, with Egyptian as with other breeds the cross-bred lambs were larger in size than the pure-bred parents.

The superiority of the cross-bred lambs over the pure-bred ones is mainly attributable to heterosis, since all lambs used in this experiment were raised under the same conditions as far as feeding and management are concerned. Moreover, the experiment was designed so that the genetic constitution of the cross-bred lambs could be compared to that of the pure-bred ones, crossings being made reciprocally using the same males to produce pure-bred and cross-bred lambs.

This investigation also showed that lambs sired by Ossimi rams were heavier and bigger in size than those produced by Ossimi ewes at birth and at 4 months of age. The difference in body weight between the two groups was 0·4 kg. at birth and 3·2 kg. at weaning age. The superiority of the cross-bred lambs produced by Rahmani ewes may have been due to the larger size of the Rahmani females [3, 4] and to the fact that Rahmani ewes produce more milk with a higher protein percentage than do the Ossimi ones [5]. Milk yield of the dam is the main factor

responsible for the growth and development of lambs before weaning, when they mainly depend on the milk of their mothers. After weaning, however, when the lambs were fed on concentrates, hay, and green fodder, there were no significant differences between the two cross-bred groups in weight and dimensions.

The advantage of using indigenous breeds of sheep for cross-breeding in tropical and subtropical countries, as a means for increasing lamb production, lies in overcoming the problem of poor adaptability of foreign breeds to local conditions. The foreign breeds are not able to stand the unfavourable environmental conditions as well as the native breeds. It should be pointed out, however, that using foreign breeds of sheep for crossing purposes will lead to still more increase in weight and better daily gain of the cross-bred lambs. Sidky [6] found that in Egypt the cross-bred lambs, Suffolk × Ossimi, were about 60 per cent. heavier at 6 months of age than the Ossimi lambs. Moreover, he reported that the daily gain for the cross-bred lambs was 0·46 lb., compared with 0·32 lb. obtained for the cross-bred lambs in the present experiment. This superiority is due, of course, to the great genetic diversity between the Suffolk and the Ossimi breed. It is desirable that imported sheep should belong to the open-faced breeds such as the Targhee and Columbia. Such breeds will stand the heat better during summer and at the same time gain more per day than the cover-faced breeds [7].

The F_1 generation produced by cross-breeding, especially when foreign breeds are used, can be utilized in developing new breeds of sheep which combine high productivity and adaptability to local environments. There are many successful examples in other countries of producing new breeds of sheep through crossing [8]. Such attempts are needed in Egypt, where the native sheep are inferior in both mutton and wool production.

The results obtained from the present experiment indicate the value of cross-breeding in increasing mutton production in Egypt, where a large amount of mutton is imported every year and the diet of the average man is deficient in animal protein. Cross-breeding would also encourage sheep breeders to produce better pure-bred animals to be utilized in crossing. Further study of the effects of crossing sheep on wool production, twinning, efficiency of food utilization, and carcass quality will add to the information needed to justify crossing as a system for breeding sheep in this country.

Summary.—A cross-breeding experiment between the Ossimi and the Rahmani breeds of sheep has been conducted for 3 years in the Animal Breeding Department, Faculty of Agriculture, Giza. 327 lambs were included in this work, comprising 110 pure Ossimi lambs, 83 pure Rahmani, 81 cross-bred lambs produced by Rahmani rams, and 53 sired by Ossimi rams.

The purpose of the experiment was to compare the cross-bred lambs with the pure-bred ones in weight, body measurements, and daily gain. Results showed that the cross-bred lambs were superior to the pure-bred animals, in all characters studied, at birth, 4 months (weaning), and 8 months of age. Differences between the cross-bred and the pure-bred lambs were statistically significant. The Rahmani ewes produced

heavier and larger cross-bred lambs than the Ossimi ones, but the differences between the two groups of cross-bred animals were significant at birth and at weaning age only.

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(*Received 8 June 1954*)

WEED CONTROL IN WESTERN CANADA

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In the greatly accelerated development of scientific agriculture in the last half century, probably no phase of the evolution has been more spectacular than that of chemical weed control. In few, if any other, areas has so intensive a weed-control programme been developed in such a short time as in the prairie provinces of Western Canada.

Emphasis on grain growing.—In the three prairie provinces, according to the 1951 census, over 40 million acres were devoted to the growing of cereal crops. Wheat comprised 23,712,174 acres, barley 7,529,784 acres, and oats 8,311,906 acres, together with a small acreage of mixed grain, grain for forage, and other miscellaneous cereal crops. Very little of this large acreage of cereals is undersown with grass and legumes. Grain growing is the mode of the area. In the drier southern part of the prairie region a very simple cropping system of alternate grain and summer fallow is practised. The rainfall is slightly higher farther north, and a three-year rotation of summer fallow, grain, grain is more common.

Summer fallow is included in the rotation primarily to conserve moisture. The theory is that less moisture is lost by evaporation from a soil surface free of plant growth than from the combined loss by evaporation and transpiration where a crop is grown. This thesis requires, therefore, that all plants, including weeds, must be prevented from growing during the summer-fallow year. Such a cropping and cultivation system would seem to be an ideal arrangement for weed control.

Over the 50 or 60 year period during which the system has been in use it has been effective in checking the growth of some weeds. This is particularly true of certain perennial weeds, such as perennial sow thistle (*Sonchus arvensis*), couch grass (*Agropyron repens*), Canada thistle (*Cirsium arvensis*), dandelion (*Taraxacum officinale*), and some of the woody perennials.

It has not proved to be a satisfactory system, however, for other weeds. Wild oats (*Avena fatua*) has thrived under the system and has become the most widespread and troublesome weed in the grain-growing area. In some areas, previous to the extensive use of chemical herbicides, common wild mustard (*Brassica kaber* var. *pinnatifida*), stinkweed (*Thlaspi arvense*), Russian thistle (*Salsola pestifer*), and other annual weeds had developed into very heavy infestations.

Early cropping and tillage methods for weed control.—Although the summer-fallow-grain system may have checked weed growth to some extent, it certainly did not provide adequate control. Other cropping and tillage practices were investigated. Rotations which included 2 or more years of sod crops were tried. These sod crops are slow in developing and it is difficult to obtain a productive stand of grasses and

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more difficult still with legumes, especially in the drier regions. Where a good stand of hay could be produced, weeds such as wild oats, Canada thistle, and leafy spurge (*Euphorbia esula*) were controlled to a considerably greater extent than with a summer-fallow-grain rotation. However, the economy in the grain-growing area does not permit a change to a mixed-farming type of rotation at the present time, so grain production constitutes almost the entire source of farm income. Concurrently with this system of farming weeds have persisted, and in many cases have increased.

Herbicides for weed control.—Into this somewhat discouraging setting, science has introduced chemical herbicides. Since these new selective products kill broad-leaved weeds without damaging the common cereals, and since the grain crops of the Canadian prairie are not undersown with legumes, this vast area has provided an ideal locale for chemical weed control to develop.

Early Chemicals used for Weed Control

One of the most common weeds, and one of the first to develop noticeably in grain crops, was common wild mustard. Because of its broad, rough, and hairy leaf, contrasting with the narrow, smooth, 'growing-tip-protected' leaves of cereals, it provided a natural medium for testing the value of a selective herbicide, especially of the contact type. One of the first of this type of spray treatments to be used was copper sulphate. While the possibilities of this material were discovered by Bonnet of France in 1896, it is believed that the first reference to its use for eradicating wild mustard in North America was by a Canadian, Shutt [1] in 1899. For some 45 years copper sulphate was employed spasmodically in this way by a few farmers, but it did not come into widespread use.

Other chemicals were introduced by various investigators in the meanwhile. These included petroleum oils, calcium chloride, sulphuric acid, hydrochloric acid, ammonium sulphate, sodium and calcium chlorates, calcium cyanamide, dinitro-orthocresol (Sinox), and others. Many of these chemicals were quite effective for some weeds, but none became outstandingly popular in weed control. The last three mentioned were used to a considerable extent prior to 1946, at which time they were partly superseded by newer developments.

Chlorates.—The chlorates, however, have continued to be used considerably in western Canada as soil sterilants. Their use for controlling weeds and brush on highways and railway rights-of-way, waste places, and in small isolated patches in fields has been very satisfactory. In 1953 it was estimated that 1,602,000 lb. of chlorate-boron compounds were used in this way in the four western provinces.

Calcium cyanamide.—Although calcium cyanamide was never extensively used for weed control, it is worthy of special mention in the development of the use of chemicals for this purpose. It was one of the first chemicals to combine herbicidal and fertilizing properties. It was applied in powder form. It required some form of moisture to make it

stick to the leaf and thus initiate its herbicidal effect. Under the more humid conditions of eastern Canada dew and high atmospheric humidity provided this moisture. In the prairie provinces moisture was not available naturally in sufficient quantities to produce this result. In 1945 Knowles [2] of the Dominion Experimental Farms Service conceived the idea of mixing small amounts of highly hygroscopic calcium chloride with the cyanamide. The mixture, although difficult to apply, did stick to the leaves and provided effective weed control. This focused attention on the moisture problem for either dust or spray methods of applying herbicides, which contributed to Knowles's discovery a year later of the low-volume spray method for applying 2,4-D in agriculture [3].

Dinitro-orthocresol (*Sinox*).—Dinitro-orthocresol, or Sinox, was becoming quite popular as a herbicide previous to 1945. It proved particularly effective in controlling wild mustard in grain crops. The leaves of the grain were burned to some extent, but since the growing tips were protected within the leaf sheath, growth was resumed soon after spraying operations, and the mustard being completely killed was selectively controlled in the grain. Furthermore the Sinox did not have a serious effect on grasses or legumes undersown in the grain. This, of course, was more important in eastern Canada than in the prairie provinces. Nevertheless, several thousands of acres were sprayed in western Canada in 1945 with this herbicide. It was effective on other weeds also, including lamb's quarters (*Chenopodium album*), stinkweed, red root pigweed (*Amaranthus retroflexus*), and a few others. It is still used to a considerable extent to spray peas, alfalfa, and clovers. In 1952 it was reported that 114,841 lb. of Sinox were sold in Canada, and since an average application is 1 lb. per acre in 80 gallons of water, over 100,000 acres were sprayed with this material.

Growth Regulators and the New Era of Chemical Weed Control

Growth regulators, hormone-type herbicides, systemic or selective weedkillers, as they are variously named, were introduced into Canada in 1945. This has resulted in a minor agricultural revolution. For many years scientists in Europe and North America had been working with plant hormones in order to stimulate the growth and production of cultivated plants. In the early 1940's evidence began to develop to the effect that over-stimulation might upset the physiological balance of plant growth, and actually destroy certain species of plants. The possibilities of this for weed control came to light in both England and the United States in 1941 and 1942.

The history of the application of this discovery is fully reviewed by Audus [4]. 2,4-dichlorophenoxyacetic acid (2,4-D) was the selective herbicide that was developed in the United States, and in 1945 extensive trials of this material were begun in Canada. Another such herbicide, 2-methyl-4-chlorophenoxyacetic acid (MCPA) was developed in Britain, but it has not been widely used in Canada to date.

Experimental work in Canada.—The introduction of 2,4-D into Canada and its possibilities aroused the imagination of scientists and

farmers alike. Extensive experimental work was set up by the Dominion Department of Agriculture and some provincial and university units, under a 'Uniform Plan' developed in co-operation with fourteen north central states of the United States. From this has developed one of the most extensive co-operative agricultural research projects ever to be attempted in Canada. A total of fifty institutions, federal, provincial, university, and private units, were co-operating in 1953 in a co-ordinated plan of investigations. These included weed-control studies such as the influence of tillage and cropping and the effect of herbicides on at least sixteen annual and seventeen perennial weeds, as well as on woody plants and poisonous plants. Extensive experiments, also, have been carried out to learn the effects of herbicides on cereal crops, legumes, grasses, vegetables, fruit crops, and ornamental plants. Weed surveys, life histories, and taxonomic, physiological, biological, and ecological studies have been undertaken. Private industry has developed a large number of new herbicides. The planning and co-ordinating of this work has been arranged by a National Weed Committee composed of representatives from the various experimental units and manufacturing companies. The results of investigations have been brought together annually and issued in mimeographed form for limited distribution.

Development and use of 2,4-D.—Based on the results of the investigational work, chemical control of weeds has developed extensively. By 1953 some 266 different herbicidal products had been registered for use in Canada. Many of these were preparations of 2,4-D. Approximately $6,000,000 worth of herbicides have been sold annually in recent years.

TABLE 1. *Acreage Sprayed with 2,4-D in Western Canada*

Year	*Area covered, thousand acres*
1945	Introduced
1946	200
1947	500
1948	4,000
1949	8,000
1950	12,000
1951	11,326
1952	13,451
1953	12,031

An indication of the rapid development and the acceptance of chemical weed control methods in western Canada may be seen in the acreage sprayed annually with 2,4-D from 1945 to 1953, as shown in Table 1.

In the last 4 years slightly less than one-third of the total grain acreage of the three prairie provinces has been sprayed with 2,4-D. Much of this spraying has been done in the Regina plains area where wild mustard was very prevalent. The weed is being reasonably well controlled there after 5 years of extensive spraying. In addition, other areas have been extensively sprayed with satisfactory results. This herbicide has been used effectively also on lamb's quarters, most of the species of mustard, stinkweed, common ragweed (*Ambrosia artemisiifolia*), and other annuals.

It is effective also with such perennials and biennials as burdock (*Arctium* spp.), dandelion, common plantain (*Plantago major*), field bindweed (*Convolvulus arvensis*), perennial sow thistle, and others.

The ester type of 2,4-D has been most extensively used. In 1953 approximately 85 per cent. was in this form. It has been recognized that this form is more active than the amine or sodium salts of 2,4-D.

Considerable damage in the way of deformed heads and reduced yields has been observed in grain crops, especially oats. In 1952 Unrau [5] reported that 2,4-D affected the plants genetically, and the Canadian Seed Growers' Association recommended against its use for *élite* and foundation-stock seed. With this in mind investigators are turning their attention to the use of milder forms of 2,4-D and to the possible use of MCPA.

Other chemicals and methods.—While 2,4-D has been widely used and has served to focus attention on chemical methods of weed control, there have been other important developments in this field of agriculture. The use of trichloroacetic acid (TCA) has developed recently. Applied at the rate of 5 to 8 lb. per acre it will kill green foxtail (*Setaria viridis*), and 80 to 100 lb. per acre will control couch grass and other grasses. Combined with preceding cultivation the application can be reduced to 50 to 75 lb. per acre. It has been reported that 81,000 lb. of this material were used in western Canada in 1953.

As previously suggested, wild oats is a most difficult weed to control, and it has become the greatest weed problem in the prairies. Disodium 3,6-endoxohexahydrophthalate (Endothal), applied at 8 lb. per acre and disked in before seeding sugar-beet, has controlled wild oats without noticeably affecting the beet. The selective control of wild oats in cereal crops such as wheat, oats, and barley or in flax has always seemed beyond the realm of possibility. Knowles [6] has reported that 1,2-dehydropyridazine-3:6-dione (maleic hydrazide) causes sterility when applied on cereal plants before fertilization of the flower takes place. Since wild oats reaches this stage later than most varieties of wheat, barley, and flax, it is possible to spray with 1½ lb. per acre of maleic hydrazide after fertilization of the cereals, and previous to that of the wild oats, and thus to cause sterility of the wild oats without seriously affecting the cereals. This suggests a fineness of technique in the handling of herbicides which indicates endless possibilities in selectivity.

In the meantime interest in weed control is increasing in western Canada, and new developments will be forthcoming to promote even greater control measures.

Summary

The weed situation under the grain-farming system of the prairie provinces of western Canada is summarized, and especially the history and development of selective herbicides in weed control. Many chemicals and formulations have been investigated but the introduction of 2,4-D really brought about the present wide use of herbicides on the prairie. Introduced into a primarily grain-growing area in which susceptible weeds had become extremely troublesome, its use has grown until

approximately 12 million acres of grain in the prairie provinces are sprayed annually. This represents approximately one-third of the total grain area of western Canada. Other important developments in herbicidal treatments are discussed.

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(*Received 29 June 1954*)

TURKISH OR ORIENTAL TOBACCO IN SOUTHERN RHODESIA

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PRODUCTION of Turkish tobacco is almost entirely confined to the Balkan countries, but a small, stable industry has been built up in the Western Province of the Union of South Africa and attempts have been made to establish an industry in Southern Rhodesia.

For some years prior to 1939 annual exports from S. Rhodesia were about half a million pounds weight of cured leaf. In 1946 the figure reached 4½ million pounds, but a rapid decline, due to unsatisfactory marketing arrangements and high prices for flue-cured tobacco, reduced it to 67,000 lb. in 1952. However, in order to satisfy a large potential American demand for Rhodesian Turkish leaf (i.e. Smyrna type) attempts are being made to expand present production.

TABLE 1. *Soil Data for Sites of Turkish Tobacco Experiments in Rhodesia*

Centre:	*Bulawayo*	*Trelawney*
Description	*Pinkish-brown, fine- to medium-grained alluvial sand*	*Greyish-brown coarse sand*
	%	%
Clay . . .	5·5	2·1
Silt . . .	1·0	6·0
Combined sands	93·5	91·9

Very little information on this crop is available in English. This paper presents the results of experimental work recently done in S. Rhodesia together with some general background information on the crop.

An essential feature of Turkish tobacco-growing is to keep down the leaf size [1]. This is normally done culturally by close spacing and environmentally by growing on soils poor in nitrogen under poor rainfall conditions. If the last two restrictions are removed growth becomes profuse in proportion to the stimulus provided and in the extreme case coarse unsaleable leaf is produced.

Experimental.—The greater part of the work was carried out at Trelawney (65 miles NW. of Salisbury), following some early work near Bulawayo. Details of the soils at these two centres are given in Table 1: both soils were very sandy.

Most of the experiments were single replicates of factorial designs, frequently employing confounding, and they were analysed by the appropriate standard methods [2]. Plot sizes varied from $\frac{1}{40}$th to $\frac{1}{165}$th of an acre, with the latter standard in 1952–3. After the 1951–2 season the normal spacing was changed from 6 to 9 in. between plants set in

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rows 18 in. apart. At the same time ridge planting was substituted for planting on the flat, with the preplanting application of fertilizer in a band 4 to 5 in. beneath the ridge, instead of broadcast. Top-dressings were applied throughout along the rows. Other cultural practices followed those described by Brown [3].

For each plot the yield of cured leaf, in pounds, was recorded together with a grade index for quality. The grade index was derived from the proportion of the various grades amongst the cured leaf, the exact method being modified from time to time in attempts to improve the grading system. Consequently grade and crop indexes were not comparable from year to year. The product of yield per acre and grade index is known as crop index; it was recorded correct to the nearest hundred.

The standard variety used throughout was Soulouk (probably this should be Ayasolouk).

Varieties

History.—The extreme oriental type of tobacco is obviously different from the common Virginia-type varieties of the U.S.A. However, certain oriental varieties grown under suitable conditions in America have shown a resemblance to Virginian tobacco now cultivated there [4]. The similarities were most marked with oriental varieties known to have a relatively short history in Balkan countries. This suggests a common origin and it is known that tobacco was introduced into Turkey in the seventeenth century.

TABLE 2. *The Main Characteristics of Four Types of Oriental Tobacco*

Type	*Origin*	*Aroma*	*Body*	*Flavour*	*Combustibility*	*Nicotine content*	*Fertilizer reqt.*	*Use*	*Ref.*
Smyrna	Turkey	Excellent	Mild	Mild	Average	Low	Moderate	To blend with stronger tobaccos which lack aroma	[7]
Samsoun	Black Sea Coast	Fair	Medium	Delicate and agreeable	Excellent	High	Low to moderate	To blend with, and improve quality of, other tobacco	[7]
Kavalla	Greece	Fair	Thin	Pleasant, and delicate	Average	Low	Low	General cigarette manufacture	
Xanthi	Greece	Good and fragrant	Thin	Very pleasant, mild and slightly sweet	Average	Low	Low (likes thin soils near mountain tops)	To impart aroma to fine quality cigarettes	[6] [8]

TABLE 3. *Details and Results of Four Variety Trials*

Centre:		*Bulawayo*						*Trelawney*			
		1948–9 6 × 6 *Latin square*			*1949–50* 3 × 3 *lattice*			*1949–50* 6 × 6 *Latin square*	*1950–1* *Randomized block—five replications*		
Variety	*Type*	*Yield lb./acre*	*Grade index*	*Crop index*	*Yield lb./acre*	*Grade index*	*Crop index*	*Yield lb./acre*	*Yield lb./acre*	*Grade index*	*Crop index*
Soulouk	Smyrna	552	14·9	82	864	13·0	112	932	501	38·2	191
Fynn Soulouk	Smyrna	645	16·5	106	..	..	..	910	..	..	..
Union Soulouk	Smyrna	658	15·6	103	892	13·2	118	926	574	38·3	220
Elsenberg Turk	Smyrna	632	15·8	100	765	13·4	102	759	561	36·1	202
Giaourkeuy	Smyrna	..	..	..	625	13·6	85	..	406	39·6	161
Kavalla	Kavalla	217	11·8	26	489	14·3	70	540	392	30·8	121
Samsoun	Samsoun	391	15·2	59	686	15·4	106	763	455	38·5	175
1st Sokhum	Samsoun	..	..	..	794	14·6	116	..	..	..	..
2nd Sokhum	Samsoun	..	..	..	620	14·1	87	..	..	..	..
3rd Sokhum	Samsoun	..	..	..	871	14·9	129	..	..	..	..
Standard error		*	*	*	*	*	*	±64	±28	±0·7	±10

Basal dressing: about 150 lb. per acre 3:9:9 tobacco fertilizer to each experiment.
* Not available.

TABLE 4. *Adjusted Mean Yields, Grade and Crop Indexes for Seventy-two Varieties*

8 × 9 rectangular lattice (two replicates)

Variety	*Received from*	*Yield lb./acre*	*Grade index*	*Crop index*
	(S.E.)	(±54)	(±0·73)	(±10)
TYPE: SMYRNA				
S.R. Soulouk	..	614	23·4	144
N.R. Soulouk	N. Rhodesia	712	19·8	139
Argos	Greece	597	23·1	135
Union Soulouk	Union of S. Africa	557	23·7	133
Sari 23	Cyprus	562	22·2	126
Smyrna 1	Greece	618	20·0	123
Giaourkeuy	Turkey	607	18·9	117
Smyrna	Cyprus	583	19·2	112
No. 8	..	559	19·6	108
Izmir (Kavur-Key)	Turkey	592	18·2	108
Sari 1	Cyprus	572	18·4	105
Giaourkeuy × Soulouk (F_1)	× in S. Rhodesia	548	19·3	105
No. 6	..	458	22·4	102
No. 6A2	..	414	23·1	95
N.R. Monopoly	N. Rhodesia	512	18·4	94
Izmir (Akhissar)	Turkey	492	18·8	93
No. 6A	..	443	20·0	89
Elsenberg Turk	Union of S. Africa	375	23·7	89
Alu Hissar	..	471	18·1	86
No. 7 × Soulouk (F_1)	× in S. Rhodesia	467	18·3	85
No. 7	..	356	22·4	79
Sari 2	Greece	393	18·2	70
No. 6 × Soulouk (F_1)	× in S. Rhodesia	419	22·7	63
TYPE: BLACK SEA COAST OR SAMSOUN				
Tik-Kulak (Rotbl Linz)	Poland	566	19·8	113
No. 9	..	504	21·0	107
Samsoun (Tarshihaya)	..	529	19·5	104
G1–49	..	425	19·6	82
Samsoun 1	..	410	19·7	82
2nd Grade Sokhum	Turkey	429	18·2	78
Samsoun 2	..	429	18·0	77
Russian type	..	413	18·1	75
Samsun	Greece	361	20·8	75
Pure Sokhum	Turkey	384	18·2	71
No. 1	..	371	18·2	67
Bachi-Bagli (Prossotsan)	Greece	364	18·1	66
N.R. Maden	N. Rhodesia	374	18·0	66
No. 10	..	346	18·4	64
Djanik Bald Jali	N. Rhodesia	349	18·5	64
3rd Grade Sokhum	Turkey	333	18·0	61
No. 4	..	328	18·1	59
Trebizond	..	312	18·3	57
No. 3	..	287	18·0	54
N.R.T.S. 5	N. Rhodesia	276	18·0	50
No. 2	..	274	18·1	49
Bachi-Bagli	..	256	17·8	45
No. 5	..	251	17·9	44

TABLE 4—*continued*

Variety	*Received from*	*Yield lb./acre*	*Grade index*	*Crop index*
	(S.E.)	(±54)	(±0·73)	(±10)
TYPE: KAVALLA				
Kavalla 3	..	419	20·2	80
Kavalla 1	..	302	18·3	56
Kavalla 2	..	258	18·0	48
TYPE: XANTHI				
Prilep	Jugoslavia	422	21·3	91
Xanty Yaka	Italy	382	18·3	68
Jaka	Jugoslavia	356	18·2	64
Xanthi Yaka	Greece	338	18·7	63
Serres	Greece	349	18·2	63
Adriani 18	Bulgaria	302	19·1	58
Prilepska Basma	Jugoslavia	254	18·9	47
TYPE: SEMI-ORIENTAL				
Yarre Ysere	Macedonia	740	22·5	160
Tombac	..	538	18·5	105
Erzgovina 93	Italy	509	18·5	95
Otlja	Jugoslavia	364	18·7	68
Trapezunt Linz	Poland	339	18·1	61
Blatec	Jugoslavia	362	18·0	51
Zletevo	Jugoslavia	175	18·2	32
UNCLASSIFIED				
Stanimaschko Pembe	Bulgaria	581	18·7	115
Zichna	Greece	439	18·8	83
No. 6 × Kavalla	× in S. Rhodesia	406	18·9	81
Perustitza N.	Italy	387	18·0	68
Tsembeli D'Ayzinion	Greece	447	18·0	63
Nerwcopsska Basma	Macedonia	264	20·5	56
Basma de Machala	Greece	277	18·8	52
Mavros	Greece	274	18·5	50
Basma de Drama	Greece	256	18·3	44

Psareva [5] lists the following main characteristics of oriental tobaccos: (1) high aroma; (2) pale lemon-yellow to reddish cured leaf; (3) plant height about 47 in. with 24–30 reapable leaves; (4) leaf length 3 to 10 in. with width $\frac{1}{3}$ to $\frac{1}{2}$ this figure.

Areas of production are given as Turkey, Greece, Bulgaria, Jugoslavia, and the Soviet Union, the tobacco being grown on light mountain soils.

Among tobaccos having these characteristics can be distinguished four types [6]: Smyrna, Samsoun or Black Sea Coast, Xanthi, and Kavalla. Each produces a characteristic cigarette tobacco the precise quality of which will depend upon the locality of production. The tobacco of any small locality will be a variety of the type grown in that area. Table 2 lists the main characteristics of each type.

Comparative experiments.—Tables 3 and 4 give the details and results of the experiments carried out. The results of Table 4 were analysed by standard methods [9].

These tables show considerable variation between the varieties of each type and even between different strains of what had been considered a single variety. However, the general superiority of the Smyrna varieties for yield, and particularly quality, is apparent.

Leaf produced by the Samsoun varieties was thin but of good texture. Lack of weight per leaf was partly responsible for lower yields and grade indexes compared with the Smyrna varieties. Nevertheless, the performance of the best Samsoun varieties suggests the possibility of producing this type of leaf commercially provided a market for it can be developed.

Xanthi and Kavalla varieties gave low yields of poor-quality tobacco. Leaf of both types was thin and frequently of very poor texture, probably because growth conditions in S. Rhodesia are too favourable for them.

The semi-oriental varieties have no present use in S. Rhodesia.

The unclassified varieties are of low performance and need not be considered further.

Some experiments confined to Smyrna varieties have been carried out but a high experimental error reduced the value of the results and they are not reported here. Future work would, however, be concerned with these varieties, probably concentrating on the production of a uniform strain of Soulouk, having a better performance than the stocks at present in use.

Production of Seedlings

In S. Rhodesia the methods used to produce Turkish tobacco seedlings are very similar to those used in the production of flue-cured

TABLE 5. *List of Seedbed Experiments Carried out in 1952–3*

Factors	*Site*	*Design*	*Plots per block*	*Replications*	*Plot size (ft.)*
Weed control . .	2nd year semi-vlei	Randomized blocks	8	3	$7\frac{1}{2} \times 3\frac{1}{2}$
Rates of seeding . .	,,	,,	5	4	$6 \times 3\frac{1}{2}$
Amounts of nitrogen, phosphate, and potash	1st year sandy, semi-vlei	3×2^2	4	2	$7\frac{1}{2} \times 3\frac{1}{2}$

seedlings [10]. Differences are largely due to sowing later in the season. Brown [3] lists the precautions required because of sowing in the period of heavy rains.

Table 5 gives the details of experiments carried out in the 1952–3 season, and the results are given in Tables 6–8. Seedlings were pulled in the normal manner [3] and numbers recorded for treatment comparisons.

The weed experiment did not demonstrate any practicable alternative

to burning for control of weeds, and Table 6 shows the increase in seedling numbers, particularly at the first pulling, due to this treatment. The soaking treatments (Nos. 3, 4, and 5), designed to germinate the weed seeds before sowing the tobacco so that they could be raked off, failed in their object. Under the conditions of this experiment 2,4-D

TABLE 6. *Total Plant Numbers per Plot from Seed-beds Treated with Various Methods of Weed Control*

Treatments	*1st pulling*	*Total*
1. Untreated	403	895
2. Burned	935	1,349
3. Watered 1 week before sowing and covered with grass	418	873
4. Watered twice before sowing, at 14 and 7 days, and covered with grass	536	1,052
5. Watered three times before sowing, at 21, 14, and 7 days, and covered with grass	325	739
6. 1 lb. per acre 2,4-D amine 1 week before sowing and kept moist as (3)	NIL	116
7. 1 lb. per acre 2,4-D amine 2 weeks before sowing and kept moist as (4)	235	573
8. 2 lb. per acre 2,4-D amine 2 weeks before sowing and kept moist as (4)	NIL	157
S.E.	±88	±133

Three pullings at 42, 48, and 58 days.

amine failed to decompose in the time allowed and it seriously affected the germination and growth of the tobacco.

Table 7 shows the close relationship between seeding rate and numbers of plants produced. The quality of the plants, however, decreased with increasing density. Rates of 1·4 and 1·2 oz. per 300 sq. yds.

TABLE 7. *Total Plant Numbers per Plot from Various Rates of Seeding*

Rate of seeding (oz. per 300 sq. yds.)	*Total*
0·6	926
0·8	1,158
1·0	1,289
1·2	1,607
1·4	1,705
S.E.	±85

Three pullings at 42, 48, and 58 days.

produced a uniform mass of spindly plants mostly unsuitable for planting. A density of about 10,000 plants per 25 sq. yds. of seed-bed is satisfactory, and Table 7 shows that this can be achieved with a seeding rate of between 0·6 oz. and 1 oz. per 300 sq. yds. Growers use rates in excess of 2 oz. per 300 sq. yds., and this is too high.

Table 8 shows a significant (P = 0·01) increase in plant numbers from a high dressing of phosphate and a significant (P = 0·05) decrease in numbers from an application of potash. These results confirm the findings of Mandelson [11] for flue-cured seedlings. The response to rate of nitrogen application was anomalous. 50 lb. per acre gave a significant (P = 0·01) increase over 25 lb., but an additional increment did not increase the number of plants (Table 8). Mandelson [11] obtained a response from nitrogen for vigour only. The low figures in this table were due to heavy rains at the time of germination and to a sandy site.

TABLE 8. *Total Seedling Numbers per Plot Obtained with Different Rates of Nitrogen, Phosphate, and Potash*

lb. per acre N			*lb. per acre* P_2O_5		*lb. per acre* K_2O	
25	*50*	*75*	*420*	*840*	*Nil*	*300*
391	521	455	413	499	496	416
	±26		±18		±18	

The design used in this experiment was one given by Thompson [12]. For unconfounded effects, the gain in precision from the use of small blocks was 190 per cent. In spite of the loss of ¼ information on the main effect of nitrogen, due to the confounding employed, the net gain on this effect was 116 per cent.

Time of Planting

Turkish tobacco requires rain only during the first 6 weeks after planting (3 to 4 in. is adequate) and the best quality leaf is produced when hot, dry conditions prevail for the remainder of the growing and reaping period. It is therefore planted towards the end of the wet season, but rainfall in S. Rhodesia is very erratic at this time and it is difficult to choose the ideal planting date in any one year. For instance, at Trelawney the period after 14 February 1953 received double the amount of rain that fell in the corresponding period of 1952.

The effect of planting late is indicated by the means for the two experiments shown in Table 11, below. Experiment N2 had a mean yield 27 per cent. less than experiment N1, which was planted 2 weeks earlier and received 0·91 in. more rain. The higher quality of leaf from the former experiment was insufficient to compensate for the large difference in yield. Conversely, the grade index for the first planting in Table 13 showed the effect of planting too early.

The results of these experiments agree with the widely held view that, in the Mashonaland area of S. Rhodesia, the best average returns from Turkish tobacco will be obtained from mid-February plantings. Within fairly narrow limits earlier planting than this will tend to favour yield, and later planting, quality.

Spacing

Three spacings were compared in four experiments, three with low rates of fertilizer application (Table 9) and one using higher rates (Table 14).

Yield and quality were not appreciably affected by having less than

TABLE 9. *Mean Yields for Three Spacing Experiments with Grade and Crop Indexes where Available*

Place:		*Bulawayo*	*Trelawney*						
Year:		*1949–50*	*1950–1*			*1951–2*			*Mean yields for all years*
Spacing (inches)	*Approx. density/acre*	*Yield lb./acre*	*Yield lb./acre*	*Grade index*	*Crop index*	*Yield lb./acre*	*Grade index*	*Crop index*	
18 × 4	87,750	587	431	39·8	173	740	31·6	232	586
18 × 6	58,500	700	381	37·5	143	735	31·8	233	605
18 × 9	39,000	645	436	38·6	168	747	31·4	234	606
	S.E.	*	*	*	*	± 33	± 0·58	± 10	*

Basal dressing: about 250 lb. per acre 3:9:9 tobacco fertilizer to each experiment.
* Not available.

9 in. between the plants (Table 9), but with heavier application of fertilizers (Table 14), although grade index remained unaffected, the 4 in. spacing yielded significantly ($P = 0.01$) less than the 6- and 9-inch

TABLE 10. *Fertilizer Experiments Carried out at Trelawney in 1951–2 and 1952–3*

Designation	*Factors*	*Type of land*	*Design*	*Plots per block*	*Replications*	*Plot size (acre)*	*Planting date*	*Rainfall (in.)*
N1	Rate, form, and time of application of N	Reverted 1st year	3^3	9	1	1/100	14.2.52	3·71
N2	Rate, form, and time of application of N	Reverted 1st year	3^3	9	1	1/100	27.2.52	2·80
NPK	Rate and time of application of N, P, and K	3rd year	3^3	9	2	1/100	19.1.52	13·99
N3	Rate, form, and time of application of N and date of planting	3rd year	3^4	9	1	1/165	*	*
NPKS	Rate of N, P, and K and spacing	3rd year	3^4	9	1	1/165	4.2.53	12·55
NK	Rate and time of application of N and K	Virgin	3^4	9	1	1/165	27.1.53	15·22

* See Table 13.

spacings. Increasing the population per acre above 40,000 appeared to stunt growth, delay flowering (cf. Table 14), and decrease leaf size without any appreciable gain in quality; these effects were not countered by higher applications of nitrogen.

Fertilizing the Crop

The soil at Bulawayo (Table 1) tended to produce coarse tobacco without any added fertilizers and was eventually considered too rich even

for Smyrna varieties. Two manurial experiments carried out there gave no response to any treatment.

A list of the experiments carried out at Trelawney is given in Table 10. 'Rainfall' includes that falling from date of planting to completion of harvest.

Main effects of treatments are given in Tables 11–15. Table 16 shows the effect of split dressings of nitrogen at each level on the crop index.

TABLE 11. *Mean Yields, Grade and Crop Indexes for Main Effects of Treatments in Two Nitrogen Experiments (N1, N2) Carried out in 1952*

	Yield lb./acre		*Grade index*		*Crop index*	
	N1	*N2*	*N1*	*N2*	*N1*	*N2*
Rate of nitrogen (lb./acre)						
3	849	669	32·2	35·6	273	239
6	893	645	30·8	35·3	275	227
12	921	625	32·7	34·3	302	215
Form of nitrogen						
100% NH_4	821	654	32·9	35·8	270	235
50% NH_4+50% NO_3	963	660	31·4	34·4	302	227
100% NO_3	879	623	31·5	35·1	277	218
Time of nitrogen application						
All before planting	845	625	31·0	35·7	262	224
½ before+½ 21 days after	919	694	32·2	34·9	296	242
All at 21 days after	898	619	32·5	34·7	291	215
General mean	888	646	31·9	35·1	283	227
S.E., treatment mean	±84	±47	±0·18	±0·83	±27	±18

On first-year reverted land (Table 12) 12 lb. of nitrogen significantly ($P = 0{\cdot}01$) raised yield and crop index over 3 lb. and 6 lb. Similarly 36 lb. of a 1 : 1 mixture of phosphate and potash significantly ($P = 0{\cdot}01$) raised yield and crop index over 6 lb. and 12 lb.

Table 11 shows no significant effects from using different rates, forms, or times of application of nitrogen. However, the high S.E.'s per plot, of 28 per cent. for experiment N1 and 22 per cent. for N2, reflect the inadequacy of single replicates of the 3^3 design for separate consideration in this type of work. Furthermore, the choice of non-linear treatment levels has precluded the simple extraction of linear and quadratic components from treatment effects.

Like those in Table 11, the treatment levels shown in Table 12 were poorly chosen, although here two replicates were used and the S.E. per plot was reduced to 16 per cent. Moreover, in this experiment the effects of rates of phosphate and potash cannot be separated.

These defects were remedied in the experiments laid down in the following season (Tables 13, 14, and 15).

TABLE 12. *Mean Yields, Grade and Crop Indexes for Main Treatment Effects of* NPK *Experiment in 1951–2*

	Yield lb./acre	*Grade index*	*Crop index*
Rate of nitrogen (lb./acre)			
3	634	31·7	202
6	632	33·3	209
12	744	33·3	248
Rate of phosphate and potash (lb./acre)			
6	620	32·1	200
12	640	32·6	209
36	749	33·4	250
Time of application			
All before planting	617	32·5	201
½ before + ½ 21 days after	629	32·6	206
All 21 days after	764	32·9	253
S.E.	±22	±0·30	±8

TABLE 13. *Mean Yields, Grade and Crop Indexes for Main Treatment Effects of Nitrogen Experiment in 1952–3*

	Rainfall (inches)	*Yield lb./acre*	*Grade index*	*Crop index*
Nitrogen (lb./acre)				
8	..	479	25·8	125
16	..	489	25·0	125
24	..	550	24·6	136
Form of nitrogen				
100% NH_4	..	509	25·2	129
50% NH_4 + 50% NO_3	..	513	24·9	129
25% NH_4 + 75% NO_3	..	497	25·2	127
Time of nitrogen application				
All before planting	..	460	25·0	117
½ before + ½ 21 days after	..	506	25·1	128
⅓ before + ⅓ 21 days + ⅓ 42 days after	..	553	25·3	140
Date of planting				
14 January	17·54	454	18·2	82
30 January	14·03	542	27·8	150
16 February	7·38	523	29·4	153
S.E.	..	±23	±0·20	±6

TABLE 14. *Mean Percentage Plants in Flower at Twelve Weeks and Mean Yields, Grade and Crop Indexes for* NPKS *Experiment in 1952–3*

	Per cent. flowers open	*Yield lb./acre*	*Grade index*	*Crop index*
Nitrogen (lb./acre)				
8	21·5	568	29·6	168
16	33·7	579	28·9	167
24	42·6	633	28·3	179
Phosphate (lb./acre)				
30	34·4	588	29·0	169
60	30·4	591	29·1	172
90	32·9	601	28·9	173
Potash (lb./acre)				
16	34·5	597	28·5	169
32	32·5	594	29·1	172
48	30·9	588	29·4	173
Spacing (inches)				
18×4	25·0	544	29·4	159
18×6	37·8	611	28·8	174
18×9	34·8	624	28·8	180
S.E.	±2·16	±16	±0·24	±4

TABLE 15. *Mean Percentage Plants in Flower at Twelve Weeks and Mean Yields, Grade and Crop Indexes for* NK *Experiment in 1952–3*

	Per cent. flowers open	*Yield lb./acre*	*Grade index*	*Crop index*
Nitrogen (lb./acre)				
16	21·8	518	26·8	138
24	27·6	593	26·6	156
32	37·8	654	26·1	170
Potash (lb./acre)				
32	27·1	569	26·9	153
48	31·0	601	26·0	155
64	30·3	595	26·5	157
Time of nitrogen application				
All before planting	31·1	479	26·4	125
½ before + ½ 21 days after	34·3	595	26·1	155
⅓ before + ⅓ 21 days + ⅓ 42 days after	22·1	691	26·9	186
Time of potash application				
All before planting	27·5	551	26·5	145
½ before + ½ 21 days	30·3	588	26·3	155
½ before + ⅓ 21 days + ⅓ 42 days	30·5	625	26·6	165
S.E.	±1·88	±15	±0·24	±4

On virgin soil (Table 15) 32 lb. of nitrogen significantly ($P = 0.05$) increased yield and crop index over 24 lb. which was in turn better ($P = 0.01$) than 16 lb. The appearance of the growing crop and the slight but consistent drop in grade index suggested that the highest level was beginning to produce coarse tobacco although the site for the experiment was only ploughed about 3 weeks before planting.

Using third-year land (Tables 12 and 13) higher levels of nitrogen increased yield slightly and raised crop index, but consistently lowered grade index. Yield differences were significant between 16 lb. and 24 lb. in the NPKS experiment ($P = 0.05$, Table 13) and between 8 lb. and 24 lb. in both experiments ($P = 0.05$, Table 13, and $P = 0.01$, Table 14). The decrease in grade index between the highest and lowest levels was significant ($P = 0.01$) in both experiments.

There was no evidence that any of the levels used delayed maturity (e.g. percentage flowers open, Tables 14 and 15).

Different forms of nitrogen produced no significant effects on yield or quality (Tables 11 and 13).

TABLE 16. *Mean Crop Indexes Produced by Splitting Nitrogen Applications in* NK *Experiment in 1952–3*

Nitrogen (lb./acre)	*Time of nitrogen application with respect to time of planting*		
	All before	*½ before + ½ 21 days after*	*⅓ before + ⅓ 21 days + ⅓ 42 days after*
16	116	144	157
24	131	154	184
32	128	145	216

S.E. ±6.

Splitting the dressing of nitrogen (see Tables 13 and 15) increased the yield but did not affect the quality. In Table 13 three (split) dressings were significantly ($P = 0.05$) better than one, and in Table 15 there were highly significant ($P = 0.01$) differences between each time of application or number of split dressings. As Table 16 shows, 16 lb. per acre N applied in three dressings gave a significant ($P = 0.01$) increase in crop index over 32 lb. in one dressing. The 42-day application of nitrogen delayed flowering (Table 15) but no difficulties were experienced in curing the leaf from this treatment.

Table 14 shows no response on any count to either phosphate or potash at the higher levels used in the 1952–3 season. However, as Table 15 shows, both yield and crop index responded to split dressings of potash. The lack of response to different rates of potash application suggests that leaching occurred and was rapid. The possibility of serious leaching of potash had earlier been suggested by Bathurst (private communication) from work on flue-cured tobacco.

These experiments demonstrate that current rates (3–6 lb. N per acre, 9–18 lb. P_2O_5 and K_2O per acre) of fertilizer application to Turkish tobacco on coarse, greyish, sandy soils can be safely and profitably

increased. However, levels of nitrogen require to be closely related to the history of the land in use and there is some evidence that the rate can be reduced for later plantings. The phosphate should be applied before planting but the nitrogen and potash are best split into two or three dressings.

Summary

Results of experiments with Turkish or oriental type tobacco in S. Rhodesia are reported, together with a brief historical account of Oriental tobacco.

Smyrna type varieties gave the best results but the variety Soulouk lacked uniformity.

Rates of seeding commonly used were too high. Benefits to seedling growth were obtained from burning seed-beds and no alternative method of weed control was found. Potash appeared detrimental and phosphate beneficial to seedling numbers.

The best average returns came from mid-February planting.

Care is required in the use of nitrogen, but present rates could be increased, and there was considerable advantage from splitting the dressings.

Rates of phosphate and potash could also be profitably raised above current levels, and some benefit was demonstrated from splitting the dressing of potash.

Acknowledgements

Thanks are due to Mr. G. E. Hodnett for his advice and assistance in the preparation of this paper, and to Dr. Yates for his helpful criticism.

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(*Received 21 June 1954*)

SOME OBSERVATIONS ON HATCHING RATES IN HENS' EGGS

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THE failure of incubated eggs to produce chicks represents a serious loss to the poultry industry and adds materially to the costs of stock replacement. In Great Britain it is estimated by the authors that from 30 to 35 per cent. of all eggs set fail to hatch. This assessment is based on a 1953 survey of 201 breeders and a number of hatcheries, handling between them approximately 12 million eggs per year. Similar rates appear to rule in other countries, e.g. Canada has a hatching rate of 70·5 per cent. of all eggs set at approved hatcheries [1] and the average for the Dominion is probably below that figure. Bearing in mind that well over 100 million eggs are incubated each year in Great Britain and that these eggs are usually sold at over £3 sterling per 100, the loss to the poultry industry is more than one million pounds each year, as the value of the incubator 'clear' is low and that of the dead-in-shell egg negligible.

The authors' survey, mentioned above, covered 201 breeders in different parts of the country, seven hatcheries of varying size, and a number of their suppliers. No material differences were found between hatcheries in the average seasonal hatching rates of all eggs set, and only small variations obtained between the average seasonal hatching rates over the last 5 years. These ranged from 68·5 to 70·0 per cent. At the breeding farms, where the number of eggs handled annually was substantially below those incubated at any of the hatcheries, marked variations occurred between them in any one year and also in the annual average for any one breeding farm over a period of years. Nevertheless, the general average in any year did not differ by more than 1 or 2 per cent. over the period of 5 years, nor was there much divergence from the hatcheries' average figures already cited. As a rule the hatching rates at pedigree farms tended to average from 73 to 74 per cent., as compared with 64 to 66 per cent. on non-pedigree farms. In arriving at a national average it is necessary to remember the proportion of poultry-keepers who occasionally hatch for their own replacements and who are erratic suppliers of hatcheries which are themselves usually small in size. Normally the hatching rates at undertakings of this nature are below those of the larger farms and hatcheries.

In a survey of the accredited farms in Northumberland carried out by Smithson (private communication) over a period of years, the average annual hatching rate of all eggs set varied in recent years from 64·70 to 68·96 per cent. (Table 1). The farms were for the most part small, and in few instances did the total number of eggs set exceed 15,000. The hatching rates were a little below those for the large survey already described, which dealt predominantly with breeders and hatcheries in the South and Midlands, and it may well be that the slightly lower rates

[Empire Journ. of Exper. Agric., Vol. 22, No. 88, 1954]

are attributable to climate and to the less favourable results usually obtained from small non-pedigree flocks. Table 1 also shows that, although there has been a notable improvement since the early 1930's, during the last 5 years the northern centres have failed to show any further improvement in the hatching rate of all eggs set or in hatch of fertile eggs.

Factors Lowering Hatching Rate

The main causes of eggs failing to hatch are as follows:

1. Infertility, including very early death of the embryo.
2. Incorrect mechanical conditions of incubation, as well as faulty collection, handling, and storage of eggs prior to incubation.
3. A deficiency of some nutrient essential to the developing embryo.
4. Genetic differences in the behaviour of the embryo.
5. Disease.

TABLE 1. *Summary of Hatching Results from Breeding Farms in the County of Northumberland*

Year	*Eggs set*	*'Clears' in small machines* %	*'Clears' in cabinets* %	*Total 'Clears'* %	*Hatch of all eggs set* %
1932	79,229	15·39	..	15·39	59·62
1933	39,827	14·54	..	14·54	58·49
1934	49,613	15·95	..	15·95	57·78
1948	367,915	..	..	18·25	68·36
1949	407,895	16·38	16·63	16·51	68·96
1950	449,525	10·30	13·60	13·50	64·70
1951	396,357	14·00	17·60	17·42	66·80
1952	424,208	26·70	15·90	16·50	67·60

Infertility.—Table 1 indicates the importance of the first of these five factors. The average percentage of eggs regarded as infertile was 16·01 per cent. and it has shown relatively little variation since 1932. This figure approximates to that determined in the larger survey, which was 15 per cent. For comparison, the proportion of 'infertiles and dead germs' recorded at the Lancashire Poultry Production and Progeny Trials was 14·16, 17·10, and 15·48 per cent. in 1950, 1952, and 1953 respectively [2]; here, many of the competitors participating were breeders of repute.

This evidence indicates that the average percentage of infertility over the country as a whole is fairly constant and that no appreciable change has taken place over the last twenty-two years. The percentage of 'clears' normally reported includes a number of eggs where the embryo has died at a very early stage. This stage may be sufficiently early not to be detected by careful candling by the hatcheryman. For true infertiles the postulated national average of 15 to 16 per cent. for infertile hatching eggs must therefore be reduced, but although no precise figures can be advanced it is probable that it would still be well in excess of 10 per cent. If the hatching of hens' eggs is similar to that of turkeys' [3] the figure for true infertiles would approximate to 14 per cent.

Extremely wide variations in infertility occur between individual breeding farms. The average over the year, in the survey of the northern breeders described, varied from 5·2 to 39·7 per cent. Much more extreme variations have been reported, but a figure below 5 per cent. is rare with flocks of any size. Where a high level of infertility persists, the cause is usually faulty management such as bleak, windy, and unpleasant housing conditions, or too few or too many males, and preferential mating is often a further reason for low flock fertility rates attributable to the influence of a few birds.

Controversy exists as to whether fertility is inherited and, if it is, the manner in which improved fertility may be transmitted. The subject has been investigated by a number of workers, who have reported opposing conclusions. It is evident that the degree of inheritance and the respective influences of dams and sires can only be slight.

Fertility is also influenced by age. Although it declines with increasing age in both the male and the female, the decrease is slow up to 3 years with the female [4]. Since an investigation carried out by one of the authors some years ago indicated that relatively few cocks, as opposed to cockerels, were used by breeders in this country and very few females over 3 years old were in the breeding pens, the actual effect of age on recorded fertility levels is likely to be small.

Funk [5] has shown that eggs laid in multiple clutches are more fertile than eggs laid in single clutches. This would appear to dispose of the suggestion that increasing egg production in the last decade or so has adversely influenced fertility.

Incubation and pre-incubation conditions.—The survey data from Northumberland give some information on the second factor affecting hatching rates, namely the influence of the incubator and the environmental conditions. The major reason for the increase since 1934 in the percentage of chicks hatched was a decrease in the proportion of dead-in-shell. The fertility rate remained largely unaffected. The reduction in the number of fertile eggs failing to hatch was presumably due to an improvement in our knowledge of nutrition rather than to better incubator conditions. This opinion gains credence when the kinds of incubator used at the time in Northumberland are considered. In the earlier years only table-type machines were employed. Little, if any, change has occurred in the design and construction of these incubators. Cabinet machines, on the other hand, have altered a great deal since their introduction some 30 years ago. Yet when the results for the last 4 years were divided between small and large (cabinet) incubators, the differences in hatching rates were negligible (Table 2).

None the less it remains a possibility that a fundamental study of incubator design and management, including environmental conditions, might lead to changes in methods which in turn could reduce the percentage of fertile eggs failing to hatch. Differences in the hatching rate over the season may well be due to differences in humidity, temperature, air supply, or other factors which are not obvious to the operator with incubators of popular design.

Differences in hatching rates due to pre-incubation factors such as

time and condition of storage of the eggs are capable of causing substantial variation in the numbers of fertile eggs hatching. Schmidt [6] showed that fertile eggs incubated within 7 days of being laid had an appreciably higher rate of hatching than those held for 21 days. A possible explanation has been advanced by Kaufman [7] who suggested that the delayed growth of the embryo and increased embryonic mortality in stored eggs resulted from hydrogen peroxide poisoning due to a decrease in the activity of catalase, which normally breaks down the peroxide as it is formed in the tissues. He showed that injection of glutathionine to detoxify the peroxide reduced embryonic mortality in eggs which were stored for 30 days prior to setting. In a well-run hatchery or breeding farm eggs are unlikely to be retained for much more than a week before setting, and it seems improbable that the failure of fertile eggs to hatch can be attributed to unduly lengthy periods of storage by undertakings of this calibre, although it may occur on ordinary farms.

TABLE 2. *Comparison of Hatching Rates between Small and Large Incubators, Northumberland Breeders, 1949–52*

	Hatch of all eggs set in small incubators %	*Hatch of all eggs set in cabinet incubators* %
1949	67·47	69·07
1950	69·1	64·4
1951	67·3	66·8
1952	66·9	67·6

Nutrition.—It is known that many food substances influence hatching rates of fertile eggs, and amongst them certain vitamins and minerals predominate. In many instances, the stage during incubation when death due to nutrient deficiency supervenes is specific for the individual nutrient. The effect of the nutrition of the hen on hatchability has been well dealt with by Cravens [8], although no doubt other factors remain to be identified. In view of the very high hatching rates reported with some lots of eggs, these still-unidentified factors are presumably often present in rations—but not always so and not always at the optimal level. Low hatchability on a farm can frequently be traced to gross deficiencies in the diet. With a diet based on the available knowledge of nutrition, however, only a very small proportion of hatching failures could be attributed to a straight nutritional deficiency.

In this country most breeding stock has been housed on range. It seems reasonable to assume that such stock may pick up substances which favourably influence hatching rates, but, clearly, nutrition will assume greater importance with the present trend towards intensive methods.

Genetic differences.—Both the nutritional aspect of the problem of hatching rates and the influence of incubator techniques are to some extent linked with the fourth factor affecting hatching rates, namely the individuality of the bird. It is well known that some birds and some

strains have a requirement for certain nutrients (e.g. vitamin B_2), above or below the generally accepted level. Again, variations between strains in the stage of gastrulation were reported by Hays and Nicolaides [9] who found that fresh eggs from hens with a high rate of hatching had embryos in an advanced stage of gastrulation, while eggs from birds with a low hatching rate were more often found in the pregastrula stage. The latter would hatch materially later than the former. The period required for incubation is also influenced by inbreeding, by the period of holding and the temperature at which the egg is held, by the weight of the egg [10], and by supplementing the diet with thyroprotein and thiouracil [11]. In practice, eggs that hatch later than others on the same hatching tray would probably be regarded as unlikely to hatch and treated as dead-in-shell.

Olsen and Marsden [12] found that turkey eggs could be divided at 24 hours' incubation into three groups according to the size and appearance of the blastodisc determined by candling. The rate of hatching was closely related to these three groups, the eggs showing the most advanced development having a high hatching rate of fertile eggs, while a very low rate was recorded with the eggs showing least development. The authors found that defective blastodiscs were more common in eggs that had been held for more than 7 days before incubation, and they suggested that the latter group were largely responsible for the rise in embryonic mortality which occurs around the 4th and 5th day of incubation. These findings are probably applicable to hens' eggs also, and the condition may be partially responsible for some so-called dead-in-shell and more probably for a proportion of eggs presumed to be infertile.

A somewhat similar difference was noted by Gartley, McConachie, and Cavers [13] who found strain differences in turkey eggs with respect to their readiness to hatch at 600 hours. Their findings related to the proximity of the poults' beaks to the air cell or to the shell after penetration of the air cell. From this the best time of transfer to the hatching section could be determined, for transfer before or after this stage reduced hatching rates. If these conditions also apply to hens' eggs a further cause of dead-in-shell is indicated.

Disease.—Published work suggests that this factor may be much more important than is generally believed. For example, Beaudette, Bushnell, and Payne [14] showed that an organism later identified as *Salmonella pullorum* was pathogenic to developing embryos and that infected hens normally showed a low hatching rate of fertile eggs. Subsequently these and other authors showed that both fertility and the hatching rate of fertile eggs may be, and usually are, adversely affected by the presence of *S. pullorum* in the breeding stock although its influence is not constant. *S. pullorum* is not so widespread in this country today as in the past, and it is improbable that the disease is responsible to any substantial degree for low hatching rates, although in view of the number of birds still found to be suffering from the disease it may slightly lower the national hatching levels.

Work by Taylor, Gunns, Grau, and Lepkovsky [15], however, suggests that a more common disease, infectious coryza, may exert a marked

influence on hatching rates. These workers found that in a breeding flock affected by infectious coryza and possibly also by infectious bronchitis the hatchability of fertile eggs was reduced although fertility was not affected. The poor hatching rate was in part attributable to poor shell and albumen quality; the hatching rate of apparently normal eggs was also poor, however, and the authors concluded that some other factor arising from the disease condition was causing embryonic mortality. This finding seems of major importance in view of the fact that coryza is sufficiently widespread to be a major cause of losses through lowered egg production with adult poultry. It may well be that many poor hatching rates are attributable to this disease and to others the presence of which is unsuspected.

Thus a review of the main causes of eggs failing to hatch shows that the task of the hatcheryman attempting to achieve a better hatching rate, and employing the available information, is not easy. Clearly it is not practicable to expect him to pay close attention to individual eggs during incubation, even if he were competent to assess the several physical characteristics which appear to influence the period required for incubation or the likelihood of hatching. The breeder's task in selecting strains for high hatching rates is very little easier. He may determine with some ease the fact that his strains have an above-average requirement for vitamin B_2, by the presence of clubbed down in the embryos that fail to hatch, but above-average requirements for most other nutrients are by no means easy for the breeder to determine—for the visual appearance of the dead-in-shell chick gives little guidance. His best practical policy is to select future breeding birds on high hatching levels of fertile eggs, or better still on total eggs set, with particular reference to early hatching. It seems obvious that many breeders do in fact follow a broad policy of this nature and, no doubt, instances where success has been achieved have given rise to the view that hatchability can be inherited. Nevertheless, in those cases investigated by the authors, progress in this direction has been very slow after rapid initial success.

To improve from a level of 40 per cent. or so infertility by selecting the daughters of dams with high hatching rates and to reach a figure of 16 per cent. within 2 years appears to be easy, but it is debatable whether the all-round improvement in husbandry, feeding, and general management, which often accompanies a real interest in breeding, is not primarily responsible for the improvement usually observed. Selection on this basis rarely leads to further material improvement once a figure of approximately 16 per cent. infertility (or apparent infertility) is reached.

Experimental

Two flocks on two separate farms were subjected to a policy of selection for improved hatching rates. The first (flock A) consisted of 100 White Leghorns; the second (flock B) consisted of three groups of different breeds of birds, viz. 100 Rhode Island Reds, 60 White Leghorns, and 60 Light Sussex. Approximately the same number of breeding stock was employed in each year of the experiment.

In both flocks a diet satisfactory for every known requirement was supplied *ad lib.* Table-type incubators were used for flock A, cabinets for flock B. In flock A all eggs produced were set; flock B was operated on commercial lines and eggs regarded as unsuitable were not placed in the incubator. Both flocks were mated in semi-intensive pens and the progeny reared on range, and both flocks were closed from the commencement of the experiment. In both flocks selection for the following year's

TABLE 3. *Hatching Results of a White Leghorn Flock Selected for Improved Hatching Rate (Flock A)*

Year	*Eggs set*	*'Clear' (infertiles)* %	*Hatch of fertile eggs* %	*Hatch of all eggs set* %
1948	3,093	27·2	54	38
1949	2,712	9·8	76	69
1950	2,621	9·6	86	77
1951	4,086	18·0	78	64
1952	3,210	14·0	76	65
1953	3,738	12·0	81	71

breeders was made only from those pullets of which the dam had an above-average hatching rate, but in flock A the average of the hatch was based on all eggs produced during the mating period (66 days commencing 2 February each year), while with flock B the hatching rate was

TABLE 4. *Comparison between Performance of Parent Birds and Progeny in Fertility and Hatching Rate (Flock A)*

	Dams			*Sires' dams*			*Progeny*		
	Infertiles %	*Hatch of fertile eggs* %	*Hatch of all eggs* %	*Infertiles* %	*Hatch of fertile eggs* %	*Hatch of all eggs* %	*Infertiles* %	*Hatch of fertile eggs* %	*Hatch of all eggs* %
1949	8·4	76	70	9·2	69	63	9·6	86	77 (1950)
1950	11·0	87	77	1·8	92	90	18·0	78	64 (1951)
1951	13·0	77	66	6·4	83	78	14·0	76	65 (1952)
1952	8·3	82	75	7·9	84	77	12·0	81	71 (1953)

based only on the selected eggs set. The pullets selected on the basis of the dams' hatching rates were mated with the cockerel sons of other equally successful dams.

The results with flock A are summarized in Table 3. A marked improvement was apparent over the first 2 years but there was no appreciable further increase in either fertility or hatching rate of fertile eggs. The fertility and hatching rate of fertile eggs of the parent birds each year is shown in Table 4; in spite of the usually superior performance of these parents, no material improvement in each following season after the first was achieved.

With flock B the results showed some differences between the several breeds. The results appear in Table 5. With the Light Sussex no improvement in fertility was discernible, although the hatching rate of fertile eggs improved a little. As suggested earlier this may have been due to the use of an improved ration and to greater interest. The results with Rhode Island Reds showed rather better results but there was no

TABLE 5. *Hatching Results of Three Breeds Selected for Improved Hatching Rate (Flock B)*

Breed	*Year*	*Eggs set*	*'Clear' %*	*Hatch of fertile eggs %*	*Hatch of all eggs set %*
Rhode Island Red .	1949	2,705	18	80	65
	1950	2,864	21	77	60
	1951	3,830	15	89	75
	1952	4,289	9	91	82
	1953	2,743	13	88	76
White Leghorn . .	1949	1,577	20	80	63
	1950	1,310	10	82	73
	1951	2,088	9	92	83
	1952	2,385	5	94	88
	1953	2,038	5	92	87
Light Sussex . .	1949	1,538	15	78	66
	1950	2,509	27	78	56
	1951	2,952	28	78	56
	1952	2,685	23	87	67
	1953	1,545	28	86	61
Total flock . . .	1949	5,820	18·2	79·8	65·4
	1950	6,683	21·7	78·9	61·7
	1951	8,670	18·4	86·1	71·4
	1952	9,359	12·5	91·4	80·0
	1953	6,326	14·6	89·4	76·2

TABLE 6. *Comparison between Performance of Parent Birds and Progeny in Fertility and Hatching Rate (White Leghorns, Flock B)*

	Dams			*Sires' dams*			*Progeny*		
	Infertiles %	*Hatch of fertile eggs %*	*Hatch of all eggs %*	*Infertiles %*	*Hatch of fertile eggs %*	*Hatch of all eggs %*	*Infertiles %*	*Hatch of fertile eggs %*	*Hatch of all eggs %*
1949	7	87	85	18	86	70	8	86	70 (1950)
1950	4	91	89	4	83	79	5	89	84 (1951)
1951	2	95	93	4	95	91	4	94	90 (1952)
1952	3	95	91	4	90	90	4	91	87 (1953)

substantial improvement after the first two years. The White Leghorns had a very satisfactory rate of improvement and the depression in the infertility level was most marked. The fertility and hatching rate of fertile eggs of the White Leghorn parents is shown in Table 6.

The overall figure for flock B was above 5 per cent. better than that for flock A, and this may be attributable to the commercial practice of selecting eggs. These overall figures, however, mask the superior results obtained with the White Leghorns and the poor record of the Light Sussex.

Discussion

The discordant results obtained between and within these two flocks emphasize the belief held by most poultry keepers that to achieve improved hatching rates above a certain level is extremely difficult. They emphasize too that the available knowledge gives little practical guidance.

TABLE 7. *Relation of Egg Production in Dams to Hatching Rate (Flock A)*

	Above 70 per cent. production			*Below 50 per cent. production*		
	Infertiles %	*Hatch of fertile eggs* %	*Hatch of all eggs* %	*Infertiles* %	*Hatch of fertile eggs* %	*Hatch of all eggs* %
1950	5	87	81	20	77	62
1951	11	79	70	23	74	55
1952	9	78	71	10	72	62
1953	12	82	73	22	74	58

A number of the eggs recorded as infertile were undoubtedly cases where early embryonic death supervened, but under the breeding plan followed these eggs were regarded as infertile and the parent was conse-

TABLE 8. *Hatching and Fertility Records of Dams Retained for 3 Years (Flock A)*

Year	'Clear' %	*Hatch of fertile eggs* %	*Hatch of all eggs* %
1st	5	94	88
2nd	12	73	64
3rd	11	70	62

quently penalized. High egg production during the mating season appeared no deterrent to high fertility or to reasonably high hatching rates of fertile eggs. This is apparent from Table 7, showing the results from high-laying and poor-laying dams in flock A: the high-laying dams were clearly superior. This characteristic has also been reported by Lamoreux [16].

Some of the birds in flock A showing high fertility and hatchability were retained. The average records of a group retained in 1950 and mated in subsequent years appear in Table 8. The birds continued to

evince a high level of fertility over the following two years; the retention of this characteristic during successive years has also been observed by other workers [4, 17]. The hatching rate of fertile eggs did not, however, persist at the same favourable levels, and this feature is a matter of some importance to which further research should be directed.

A number of the fertile eggs failing to hatch in flock A would undoubtedly have produced a chick if given individual treatment, i.e. change to the hatching trays[1] at earlier (or later) periods than the rest of the eggs on the setting trays. It was hoped that if uniformity of the incubation period was highly heritable, dead-in-shell eggs resulting from differences in readiness to hatch would decline through removing chicks from the incubator at a fixed time and regarding unpipped eggs (which might have hatched over a longer period) as dead-in-shell. This policy, suggested by Gartley and his colleagues [13], may have been responsible for increasing the hatch of fertile eggs over the first 2 years but it did not seem very effective in subsequent years.

Quite possibly more progress would have been made if selection on egg weight had been practised in flock A, so leading to a more uniform incubation period. This possibility gains much support from the results with the White Leghorns in flock B, where this practice was in force. The difference in the hatchability rates of the two flocks appears to endorse this method. Since egg weight is highly heritable, it is probable that selection in flock A at one hatching stage—which it seems is influenced by egg weight—would ultimately lead to fewer variations in weight between all eggs produced. On the basis of this contention it appears likely that greater progress will be made with the White Leghorns of flock A in future and that the results will approximate to that of the Leghorns in flock B.

Hutt [18] has referred to lowered hatchability resulting from inbreeding, in a case where a high coefficient of inbreeding was associated with a marked decline in hatchability. It seems doubtful, however, whether the disappointing results in flocks A and B could be attributed to this factor, for the degree of inbreeding was relatively small and in any case the White Leghorns in flock B appeared unaffected, although the degree of inbreeding was greater with them than with the Rhode Island Reds in flock B or the White Leghorns in flock A.

The degree of success achieved in the two experiments was disappointing. With the exception of the White Leghorns in flock B little progress was made in the remaining three groups in improving fertility. Rather better progress was made in improving the hatchability of fertile eggs but, with the same exception, the rate of progress was not impressive. It seems doubtful whether attention on a scale practicable for most hatcherymen to such points as variations in readiness to hatch, or placement of beak, can lead to much improvement; and unlikely that greater attention—if within the compass of the hatcheryman's abilities—would be warranted by the increased number of chicks hatched off-

[1] Only a proportion of the table machines in flock A were used for hatching, the eggs being removed at the 18th day from the machines in which they were set to facilitate pedigree work.

setting the cost of his additional labours. Most progress was made by selecting eggs of equal weight and by hatching for similar periods of incubation. It may very well be that further work on the technique of incubation and the relationship between the presence of certain diseases and hatchability offers the best hope of improving hatching rates.

Summary

Results are given of surveys of the hatching rates experienced by a large number of poultry breeders and hatcheries in Britain. It was found that total hatching rates were low, almost one-third of all eggs set failing to hatch. Both the national infertility rate (including early death of the embryo amongst eggs set), and the number of fertile eggs which failed to hatch, approximated to 15 per cent. of the hatching eggs set. Experimental work with two flocks, carried out with the aim of improving total hatching rate, is described. From the results of these experiments and those of other workers whose findings are reviewed it is concluded that:

1. Progress to reduce the flock level of infertility below 15 per cent. is extremely difficult. Selection on a basis of the performance of either or both parents does not usually lead to improvement. Fertility generally behaves as an individual characteristic, and little useful advice can be given to the breeder to aid him in improving the level of an already moderately good flock.

2. Improvements in incubator design over the last 20 years have not appreciably increased hatching rates. However, the high level of hatching occasionally recorded within a flock suggests that a fundamental investigation of conditions existing in incubators and in their immediate environment might show the possibility of some improvement. Pre-incubation handling and storage probably play a greater part than present-day incubation processes in giving low hatching rates.

3. Few fertile eggs set by experienced breeders fail to hatch because of gross nutritional deficiencies, although these may be responsible for large-scale failures amongst less-experienced poultry keepers. There are opposing views on genetic influences, yet fertility and hatchability appear to be to some degree related. Almost the same difficulty is experienced in breeding for improved hatchability as for improved fertility. The most promising advice available to the breeder is that he should select eggs of equal weight and age and, if possible, future breeding stock should be selected only from those chicks hatched from eggs having an approximately identical time-lapse between setting and pipping.

4. The influence of disease in the breeding flock, on the hatching rate of fertile eggs produced, may be greater than is generally assumed.

Acknowledgement.—The authors wish to express their grateful thanks to the A.G.C. Experimental Farm for kindly allowing them to use the flocks and resources of the centre for the experimental work described.

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(*Received 29 April 1954; as revised, 15 October 1954*)

THE INFLUENCE OF CLIMATE ON AN OUTBREAK OF WHEAT APHID IN KENYA

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THE first signs of the 1952 attack of wheat aphid, *Schizaphis* (*Toxoptera*) *graminum*, in Kenya, were observed during the beginning of August of that year. Many acres of wheat and barley, sown in May or June, were reported to be turning brown and aphids of *S. graminum* and another species, *Rhopalosiphum maidis*, were being found in large numbers. By the end of September a large acreage had been affected, mostly in the Nakuru district of the Rift valley area of the Kenya Highlands, and considerable loss had been experienced by farmers. The Agricultural Department had organized an extensive campaign of control involving agricultural and entomological staff and commercial spray contractors, which undoubtedly did much to prevent even greater damage to crops in the areas concerned.

It is unfortunate that no accurate estimations of the intensity of the attack in different places could be made at the time as it was not until the following year that this study of the climatic conditions affecting the attack was begun. There was little disagreement, however, between those concerned in the campaign as to the localities where the greatest damage occurred or the degree of infestation in other parts. The position of farms on which crops attacked by the aphid were ploughed back was finally used as a guide in compiling the map (Fig. 2), and this was fully supported by other sources of information.

To provide an idea of the area of the crop and the amount lost, the total acreage planted to wheat in the whole Nakuru area was 51,437 acres, and 10,272 acres to barley. Not all of this was affected, but at Njoro, for example, the 11,000 acres of wheat planted yielded only 2·66 bags (of 200 lb.) per acre. For comparison, the mean yield for the colony was 4·47 bags, that for another part of the district was 7·19 bags, and the average yield for Njoro over several years was 4·61 bags. There was, therefore, a loss of very nearly 42·5 per cent. of the total expected yield of approximately 51,000 bags, or 21,600 bags were lost at Njoro alone. Equivalent losses of barley were 3,075 bags (28·4 per cent.) and oats 2,106 bags (41 per cent.) at Njoro. Some of these final losses are attributable partly to drought or the depredations of grain-eating birds, and they were, of course, unevenly distributed, the damage on one farm varying from 100 per cent. to almost nil. But the losses can be seen to have justified the allocation of a large sum by government to launch the spraying campaign.

Description of the area.—Njoro, the district that suffered most from aphids and can be regarded as the centre of the infestation, is situated about 400 miles inland from the coast (Figs. 1 and 2) on the railway to Lake Victoria. Lying on the western slope of the Rift valley, with the Nakuru soda lake below at an altitude of about 6,000 ft. above sea-level

[Empire Journ. of Exper. Agric., Vol. 22, No. 88, 1954]

and cooler forest behind rising to 9,000 ft., it is part of the European farming system that covers most of the Rift valley floor from the western wall, shown by high rainfall on the left of Fig. 2, to the eastern wall, again with high rainfall, on the right. The areas devoted to European farming are those enclosed within straight lines on the map (Fig. 2). The

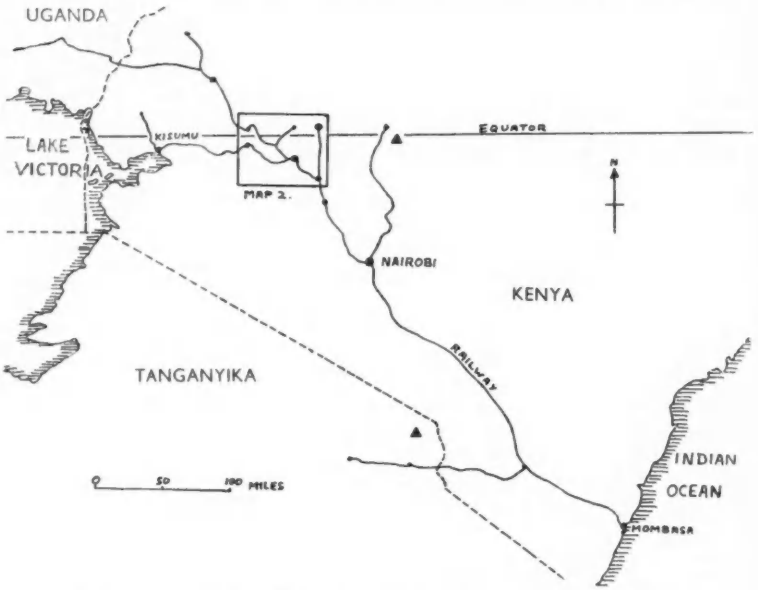

FIG. 1. Kenya, showing the position of Fig. 2 and of the railway.

portion outside these boundaries is either native reserve in which other crops are grown, forest reserve, or uncultivated bush, and hence outside the scope of this study. Apart from this farming land in the centre of the map, from Mau over to Nakuru and above, wheat and barley are, of course, grown extensively in other parts of the country, notably that starting at the top left-hand corner of the map, the Uasin-Gishu, and the Thomson's Falls valley which follows the railway line up the right-hand side of the map from Gilgil. Neither of these areas suffered seriously from aphids and reasons for this are suggested below.

This then is the rolling farming country, with its warm days and cool nights, in which greenfly was rapidly developing during the July and August of 1952 and was soon to affect a large proportion of the wheat and barley planted after the onset of the April rains.

Meteorological Conditions

Conditions prior to the 1952 attack. There was no doubt at the time that the district here called the centre of the outbreak was suffering from

a low rainfall during the months after planting, and an analysis of the monthly rainfall at Njoro (Plant Breeding Station) was therefore made for the periods before, during, and after the usual planting period for wheat. This is shown on the rainfall histogram (Fig. 3). The 1951–2 values are compared with the mean monthly rainfall taken over 22 years. Two facts stand out clearly: firstly that in 1952 the month of May was wetter than usual, and secondly that June, July, and August were very

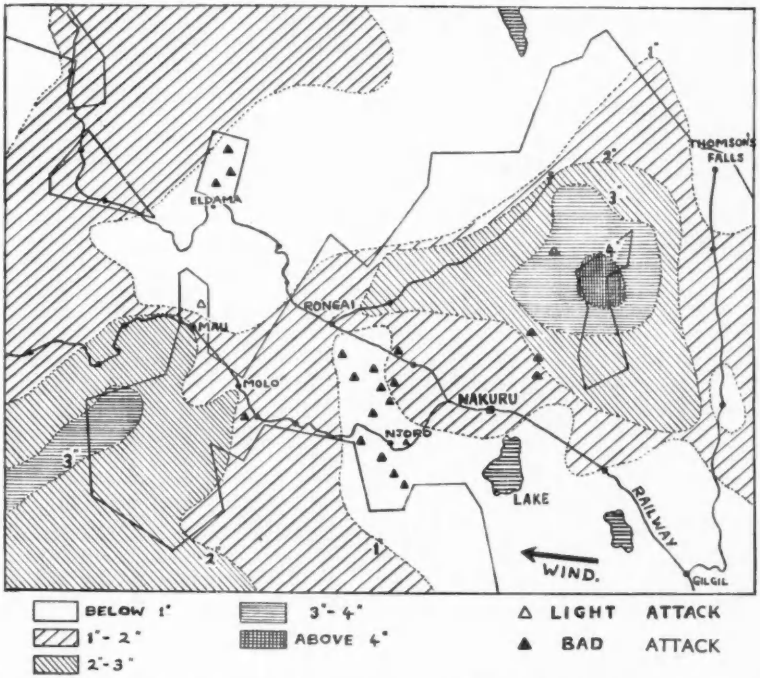

FIG. 2. The relation between aphid outbreak and the rainfall for June 1952, represented as in the key. European farming occurs only within the straight-line boundaries. (Scale, about 14 miles = 1 in.)

much drier than can usually be expected. This reduced rainfall after planting, with its obvious effect on the young wheat and barley, would appear to be one of the major conditions which caused proliferation of the aphids and their extensive damage to the crop.

Another significant feature of the rainfall histogram is to be seen in the months at the end of the previous year. The harvest months of October, November, and December 1951 were exceptionally wet when compared with the normal values. A fourth and perhaps less important feature, which may have operated more through its effect on temperature, is that a lower rainfall is discernible in January, February, and March 1952.

These four deviations from the mean rainfall for the district, a very wet

period during the harvest of the previous crop, a slightly dry first three months, a slightly wet planting period, and, most of all, a very dry spell following planting, can be discussed with reference to other serious cases of aphid outbreak in Kenya and elsewhere.

Conditions for the 1911 outbreak in Kenya. Wheat at Njoro was then virtually a new venture in Kenya, having been planted for only 5 years,

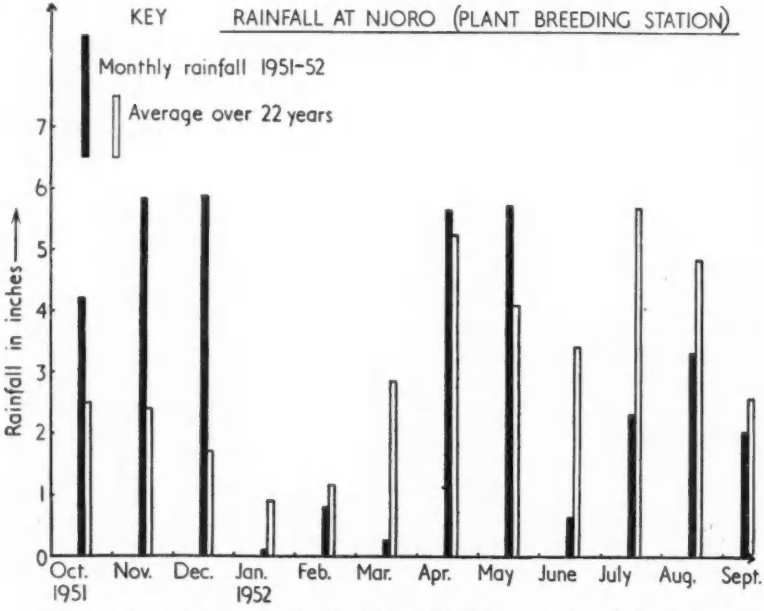

FIG. 3. Comparison between the monthly rainfall for 1951–2 and the normal over 22 years at Njoro.

and the 1911 crop was being closely watched as greenfly had been found for the first time in the previous year. From the start of the outbreak in August 1911 to September of the same year it was estimated that 50 per cent. of the crop was entirely destroyed out of more than 6,000 acres planted, and still more was damaged.

A histogram (Fig. 4) shows the rainfall for the period 1910–11 at a farm at Njoro. Wheat planted in June was most attacked and here again the dry post-planting month of July can be clearly seen. Taking for comparison the other features shown by the 1952 chart, the previous year was not obviously wet, only slightly more rainfall than the average being recorded for November 1910. But the pre-planting months were all drier than usual and the planting month was wetter. Thus, except for a previous wet harvest, the deviations from the mean found in the 1951–2 records were present in the 1910–11 records. This general similarity, and the fact that the deviation of the greatest magnitude was that of the

month after planting, lead one to consider this period in more detail and attempt to correlate low rainfall after planting with the distribution of the outbreak in 1952.

Rainfall distribution in 1952.—A map of the rainfall levels during the critical month of June 1952 was therefore drawn (Fig. 2), and the intensity of aphid attack in the main affected areas was indicated by black

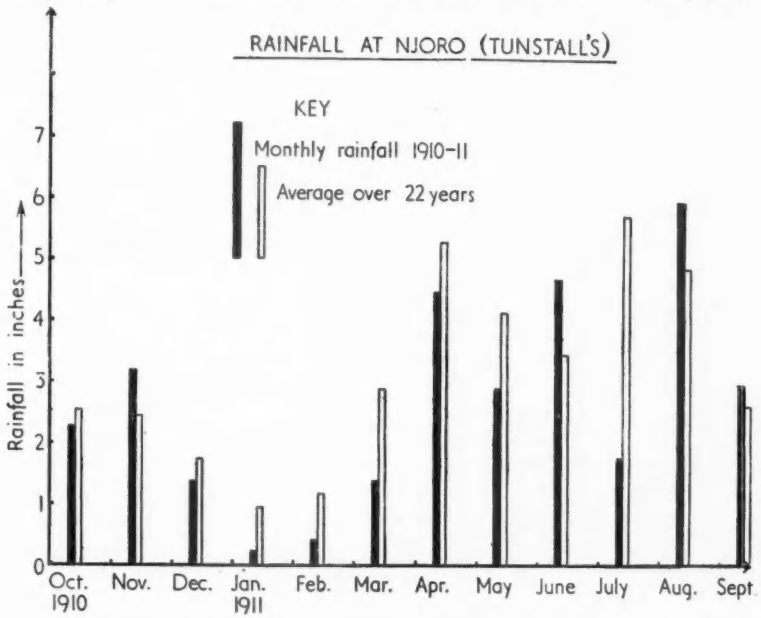

FIG. 4. Comparison between the monthly rainfall for 1910–11 and the normal over 22 years at Njoro.

triangles to represent farms where the crop was attacked sufficiently badly for it to be ploughed in, while blank triangles show the position of light attacks.

The map clearly shows how the distribution of bad attacks from Njoro to Rongai generally coincided with a total rainfall of less than 1 in. Any other badly attacked farms in this locality were situated close to this arbitrary 1-in. level, and local conditions probably operated to encourage aphid attack.

This relation was supported by conditions in the Eldama Ravine district, which similarly received less than 1 in. and was attacked by greenfly. The attack at Mau fell within the low-rainfall area but was only light, on account of the altitude of 8,500 ft. and the consequent cool temperatures prevailing. The heavy attack at Molo and those to the north-east of Nakuru remain as anomalies, that at Molo being in the 1–2-in. area and the latter scattered about the 2-in. level. In considering these attacks it should be remembered that the monthly rainfall figures

plotted on the map have a fairly wide variation from farm to farm and from day to day. As the arbitrary period of the month of June has been taken, it is possible that despite a higher total monthly fall, the period shortly after planting coincided with the driest part of the month when lack of rain would be most damaging to the young crop. Further, those farms receiving 2 in. of rain to the north-east of Nakuru often come under the same hot, dry wind that blows up to Njoro from the lower part of the Rift valley below Nakuru, but following the eastern wall, and causing transpiration loss and water deficit. In all, however, the losses in this wetter area were considerably less than those at Njoro which fell so unmistakably on and below the 1 in. rainfall level.

Areas within the European farming district which received a low rainfall and little or no aphid attack are those starting at the top left-hand corner of the map (Fig. 2), namely Ainabkoi and the Uasin Gishu, and the Thomson's Falls valley on the right. The main reason for the non-appearance of aphids in these parts would appear to be the low temperatures prevailing, as a result of a greater altitude in the first area or proximity to the cold, wet plateau of the Aberdare mountains in the second. In both these districts planting is on the whole later than at Njoro and Nakuru and the main effect of the drought on young plants would be avoided.

The distribution of aphid attack can thus be fairly closely related to the distribution of rainfall in the period following the planting of wheat and barley, with a few exceptions for which other explanations obtain.

Conditions causing outbreaks in the United States.—In the United States, where the chief seasonal variation of climate is that between summer and winter, the main element responsible for aphid outbreaks is temperature. Although this varies widely from north to south of the chief wheat-growing areas, influencing the production of sexual forms and the numbers of aphids and parasites, it has been established by numerous investigators that when a mild, wet winter is followed by a cool spring, conditions are favourable for aphid development but not for its natural enemies [e.g. 1, 2].

The observations in the United States emphasized how much effect a season which encourages multiplication and survival of aphids can have on the aphid population attacking crops that grow the next year. If the early part of this year is again in favour of the aphid but suppresses its enemies, the attack is likely to be heavy. Although the summer and winter changes in the United States are mainly due to temperature whereas East African seasons are based on rainfall, there is common to both the factor of a carry-over of a pest from one season and its multiplication under favourable conditions in the next. The influence of temperature may be comparable in the two types of climate.

Temperatures for Kenya outbreaks.—Temperatures at Njoro have been recorded for only six years prior to 1952, so that conditions in 1951 and 1952 cannot be compared with long-term averages. The figures for Nakuru, however, have a 20-year average for comparison and they have therefore been included. They bear a close similarity to those at Njoro (Table 1).

If these figures are analysed for the period before and during the 1952 attack in Kenya, a set of conditions comparable with those effecting outbreaks in America can be seen. In the first place, during the last 3 months of 1951, when harvesting of the 1951 crop was taking place, mean minimum temperatures were strikingly higher than the long-term

TABLE 1. *Monthly Mean Temperatures in the Rift Valley, Kenya* (°F.)

	1951			*1952*								
	Oct.	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*June*	*July*	*Aug.*	*Sept.*
NJORO:												
Mean minimum	47·3	48·9	48·5	45·1	46·4	47·0	49·6	49·8	43·4	45·8	45·4	44·8
7-year mean	43·9	45·5	46·0	44·6	44·7	46·3	48·2	46·7	45·3	44·1	44·3	43·3
Mean maximum	73·5	73·6	72·6	76·6	79·9	81·9	78·3	74·5	73·7	74·0	73·8	75·6
7-year mean	75·5	74·8	75·4	82·8	80·1	82·6	76·8	74·5	72·4	71·3	71·1	73·6
NAKURU:												
Mean minimum	51·2	52·5	54·9	46·8	47·9	49·6	53·7	55·0	49·5	57·3	50·7	48·9
20-year mean	48·3	49·1	49·0	47·6	48·5	50·5	52·7	52·7	51·1	50·8	50·1	48·1
Mean maximum	78·2	77·3	75·9	81·9	85·2	86·2	81·2	79·3	76·4	77·2	77·0	79·6
20-year mean	79·3	78·4	79·5	83·0	84·8	83·7	80·0	77·9	76·9	75·2	75·6	78·6

means and mean maxima were all lower, implying that the local conditions were without sustained extremes of temperature. In addition the figures for

$$\frac{\textit{mean minimum} + \textit{mean maximum}}{2}$$

were also higher for October and November 1951 at Njoro, and for October, November, and December at Nakuru, than the corresponding long-term functions. This is to say that as well as having no exceptionally cool periods, these months were also warmer as a whole than usual.

These higher temperatures were maintained to a greater or less degree until after the rains, when in the month of June 1952, with a young crop coming up and rainfall declining, relatively low temperatures were recorded. The mean maxima were not appreciably different but the mean minima were definitely lower, and an absolute minimum of 39° F. was recorded at Njoro during June. Indeed, a temperature of 40° was recorded on 11 days during the month. The significance of these low temperatures will be discussed later.

In the months following, temperatures remained consistently higher until September, by which time most of the damage had been done.

In the areas that were mentioned as suffering little from greenfly, Ainabkoi recorded mean minima of the same order as Njoro (45·5°–46·5°) but mean maxima were often 10° less. In the Thomson's Falls valley the mean minimum at Ol Joro Orok for June was 38·5°, the mean maximum was 73°, and the absolute minimum 33·5°, all of which were considerably lower than the Nakuru–Njoro–Rongai figures, and not conducive to aphid attack.

No temperature records are available for the 1911 outbreak in Kenya except for the observation by the entomologist, T. J. Anderson, that

July, when the wheat was young and rainfall poor, was the coldest month in 1911.

Other years favourable to aphid attack.—It might be expected that similar conditions arising in other years would also provide examples of greenfly outbreaks. Temperature records for other years are meagre but an examination of the rainfall records for Njoro shows only three other years with a low rainfall at this time, namely (in inches):

	June	*July*
1922 . .	0·28	4·23
1927 . .	0·0	3·13
1941 . .	1·1	7·1

No aphid outbreaks were reported for these years, but in each year the July rainfall, unlike that of 1952, was substantial. The season of the 1911 outbreak was unfortunate in that the high August rainfall came too late to repair the effects of a dry July. This aspect of the matter is complicated by the use of the monthly rainfall as an arbitrary unit and possibly by different planting dates, as well as a lack of precise information, so that further discussion is not justified.

The bearing of these conditions on aphid biology.—There are four main factors to be considered in examining the influence of climate on the numbers and spread of an aphid infestation. There is firstly the basic rate of reproduction of aphid individuals on the plants. This governs the absolute numbers of aphids which are to be found, once they are established in any particular spot. Secondly there is the development of winged forms or alatae, which provides the means of spreading the pest and forming new colonies. In the third place the flighting and dispersion of these winged forms requires an optimum set of conditions for its success. The remaining factor is concerned not with the aphids themselves but with the presence and rate of reproduction of parasites and predators which can play a large part in reducing aphid numbers. Each of these factors is directly concerned in the state of the infestation and each can be influenced by weather conditions.

(*a*) The rate of reproduction of *Schizaphis graminum* in East Africa is not known but figures are available from North and South America that give a general picture of its relation to temperature, even though they may refer to a slightly different strain. The aphid develops well over a wide range of temperatures, beginning to reproduce at 40° F. [1] and then taking about 30 days, but taking only 6 days at 70–80° [3]. For another aphid, *Toxoptera aurantii* in Palestine, Rivnay [4] found 75° the optimum for a short life-history, and development was slow below 60°. In general it is known that high temperatures and low humidity are the factors which chiefly accelerate development [5]. These factors explain the effect of a mild and warmer period from October to December 1951 in increasing the numbers of aphids while the high rainfall was encouraging a large volunteer crop. The warm period before planting maintained colonies, the cool month just after planting had more effect in reducing predators and parasites, but the high temperatures in the

months following encouraged a high rate of development and continued to ensure a high population of aphids in the affected districts.

It is difficult to prove that the condition of the plant has any bearing on the development of colonies on it, although the point has often been discussed. There is no doubt that aphid colonies prefer young tissue such as young wheat leaves, but the tenderness of the cuticle and tissues may be the reason. It would be thought that wilted plants, which are attacked the most, would have a high osmotic pressure and low wall pressure in their cells and little available water. Possibly the ease of penetration into and between flaccid cells favours plants suffering from water deficiency.

(*b*) The production of winged forms assisted in the spread of the attack over the affected area. Workers on this subject have been divided on the fundamental causes of wing formation, but it was early recognized that the state of the crop was one of them. Webster and Phillips [1] considered that when the food supply was curtailed winged forms increased, and Schaefer [6] related the increase to the inability of the plant to support the aphid population on it.

Various other workers have supported these conclusions, but Rivnay [4, 7] attributed wing formation in *Toxoptera aurantii* entirely to the water balance within the aphid. Water deficiency could be due to non-availability, resulting from low plant turgidity, wilting, and overcrowding, or to loss of water from the aphid itself caused by low air humidity and high temperature. Thus the factors encouraging massive development of winged forms were constantly present in the area attacked during the period following planting, and they caused large numbers of alatae to be produced on the wilting crop.

(*c*) The main condition governing the flight of aphid alatae in general appears to be humidity, although whether a low relative humidity [8] or a change in humidity [9] most encourages aphid flight is in dispute. High temperatures are also important. It is further probable that wind speed and direction play a large part, but no records are available for the district. Johnson [10] discussed a variety of factors concerned, including wind.

It is evident that the low humidities and high temperatures prevailing during the July and August must have had an effect on the flighting of alatae which helped to distribute the attack throughout the district. Broadbent suggested that flights tend to be short during cloudy weather and long during hot, so that the hot, cloudless days of July, August, and September would have encouraged a dispersion of alatae both far and, on account of the great convectional wind currents in the Rift valley, high in the air.

(*d*) The remaining factor to be considered is that of parasites. American studies indicated that temperature is the limiting climatic element and that outbreaks in the wheat belt usually followed the occurrence of a cool spring when the aphid increased but not the parasite complex. Webster and Phillips [1] found that *Aphidius testaceipes* was not active much below 56° while the host began to reproduce at 40°. Griot [3] gave the length of time for the full development of *Aphidius* as 10 days at

73° but 25 days at 55°. Atkins and Dahms [2] stated that rapid increase of the parasite did not occur until the daily minimum temperature exceeded 50°. Shelford [11], quoting earlier work, stated that the threshold for the aphid was 32° but 36° for the parasite.

Temperatures at Njoro during June 1952 fell to 39° and were often below 40° and would thus effectively retard similar Hymenopterous parasites. High temperatures were also mentioned by Shelford, who pointed out that the peak development of the aphid was above 80° while the parasite started to decline at 75°. The mean maximum temperature in July at Njoro was 74° and at Nakuru 77·2°, and in August 75·6° and 79·6° respectively, so that the extremes of temperature during these months were possibly significant in reducing the numbers of parasites.

In fact no Hymenopterous parasites were found during the outbreak. The only means of biological control observed to be operating were Coccinellids (*Adonia variegata*), Syrphid and other predators, and a fungus, but little information is available about their relations to climate except for some work by Johnson [12] on a predacious Coccinellid. He related high temperature to increased eating, but also to a shorter last larval stage. He considered that the latter factor predominates, and as most aphids are attacked during this stage the total amount of food taken is actually less at high than at lower temperatures.

The probability of receiving the 1952 rainfall at Njoro.—Glover and Robinson [13] have recently published a method for predicting the probability of a certain rainfall occurring at a place, based on the normal distribution. This method has been used to predict the chances of getting a dry June, with less than 1 in. of rain, a dry July, with less than 2·8 in., and a combination of the two at Njoro. The statistical population used was the mean monthly rainfall for June and July at Njoro.

Taking the June figures, the mean was 2·96 in. and the standard deviation $\pm$1·801 in., so that for a rainfall of 1 in. the 'standardized difference' was 1·088, which corresponds to a probability of 14·3 per cent. This means that such a June rainfall is likely in 14 years in a century.

The July figures gave a mean of 4·66 in., a standard deviation of $\pm$1·712 in., a 'standardized difference' of 1·068, and a probability of 13·9 per cent., or 14 years in a century. Combining the two, the 1952 June–July rainfall conditions might be expected to occur in 2 years in a century.

Discussion

Population dynamics.—Any discussion of the population dynamics of the outbreak must be largely conjectural as no quantitative estimates of the population were either known for normal years or were made during the 1952 outbreak. Counts of aphids, parasites, and predators should be made during future outbreaks, and they would give useful indications of the relative importance of climatic and biotic means of limitation, as well as the type and course of dispersion.

There would seem to be no doubt that the immediate cause of aphid increase was the sudden expansion of a suitable plant environment with the rains in April and planting in May–June. This im-

provement in conditions followed the usual hot, dry spell when both the aphid and its biotic controls were suppressed. Weather conditions after April were such that the rate of reproduction and rate of development of the aphid were accelerated and the means of dispersal favoured, with a consequent very heavy attack on the young crop. At the same time temperatures were unfavourable for parasites and predators and the population increased apparently unchecked. The amount of damage was made greater by the poor state of the crop, due to drought, those fields which were well established suffering less than those planted later.

The influence of the preceding wet harvest is difficult to assess as the hot, dry period between this and the 1952 planting would be expected to reduce the numbers of aphids to their customary low level. As nuclei of aphids must have been present in isolated favourable places, the wet harvest of 1951 might have given rise to a larger population and a greater potential in such nuclei.

Alternatively the numbers of aphids outside the outbreak centres might have risen and those in the area could have been increased by migration, but this seems less likely when the region is considered as a whole. The area would in fact appear to be one of the areas of 'occasional abundance' described by Cook [14], where insects are always present but are limited by conditions, in this case both climatic and biotic, which are only occasionally removed.

The campaign of spraying with insecticide was intended both to control the pest and to prevent its outward spread from the centres of the Njoro, Rongai, and Nakuru districts, but if climatic influences outside these centres were as effective in suppressing the aphid as this analysis suggests, there was in any event little likelihood of serious attack in the cooler, higher districts bordering the area. The final distribution of the aphid was complicated by the insecticide spraying, but there appeared to be little damage in these unfavourable districts by the time the attack died out.

Although further consideration of the development and distribution of the outbreak is impossible in the absence of quantitative data, this brief discussion shows that by studying the population dynamics and climate in such a single and well-defined area it may be possible to elucidate the causes and normal means of control of similar attacks. Such a study may also greatly influence the way in which control by insecticides is planned and carried out.

Summary

The outbreak of wheat aphid that occurred in Kenya in 1952 was found to be most distinctly associated with low rainfall just after planting and with a high rainfall and mild conditions the previous year. Temperature was less significant but compared with the conditions obtaining for outbreaks in the United States.

An earlier outbreak in Kenya was analysed and the conditions were found to agree with these conclusions. The probability of such conditions recurring is calculated and their bearing on aphid numbers and dispersal is reviewed.

Acknowledgements.—This study was made while the writer was working on insecticide problems under the direction of Dr. R. H. LePelley, Senior Entomologist, Scott Agricultural Laboratory, Nairobi. He is indebted to J. F. Graham and S. Kockum of the Laboratory and F. A. Rabagliati, Agricultural Officer, Nakuru, for valuable help and discussion of the problem, and to B. W. Thompson and other members of the East African Meteorological Department for their advice and much patience in assistance with records.

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EFFECTS OF CALCIC AND MAGNESIAN LIMING MATERIALS ON THE CALCIUM AND MAGNESIUM CONTENTS OF CROPS AND PASTURE

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IN recent years there have been many cases of tetany in stock associated with a low magnesium content in the blood [1, 2, 3]. Although there does not appear to be any evidence that this trouble is associated with a shortage of magnesium in the soil, there is a scarcity of information, particularly for Scottish conditions, on the seasonal variation in the magnesium content of pasture and on the effects of supplements containing magnesium on the amounts of this element in crops. The following is an account of experimental work undertaken to study (*a*) effects of calcic and magnesian liming materials on the magnesium and calcium contents of crops including mixed pasture, and (*b*) seasonal variation in the magnesium content of pasture.

Experimental.—Experiments involving 'lime' and 'no lime' treatments were carried out at five centres. Details are given in Table 1 of the original pH, CaO, and MgO values of the experimental soils, the rates of application and the calcium and magnesium contents of the liming materials, and the associations to which the soils belong. The results for the first 4 years of the long-term liming experiments at Craigiebuckler and Wedderhill II, where the treatments were arranged in lattice and latin square designs respectively, have been reported by Reith and Williams [4]. Results for only a few of the treatments in those experiments are considered here. The experiment at Sunnybrae is being carried out by the Crop Husbandry Department of the North of Scotland College of Agriculture, the three treatments being randomized in each of two blocks. At these three centres a range of crops, including mangolds, fodder beet, sugar-beet, swedes, turnips, marrow-stem kale, thousand-headed kale, barley, oats, and hay, has been grown and samples of them have been analysed.

The experiment at Drimmies was laid down on pasture for one season only and the four treatments, which included one with 10 cwt. $MgSO_4.7H_2O$ per acre, were randomized in each of two blocks. Samples of mixed herbage were taken at intervals of 2 to 4 weeks on six occasions between April and the end of August, the samples from the individual plots at each cutting being analysed separately. The grass was cut and removed after each sampling. In the Ardtannes experiment there were five treatments arranged in a latin square design, and the lime dressings were applied on the ploughed land in the spring of 1949 before an oat crop, undersown with grass and clover seeds, was grown. During the 3-year period 1950–2 this experiment was in grass which was sampled regularly at intervals of 2 to 4 weeks depending on the amount of growth.

[Empire Journ. of Exper. Agric., Vol. 22, No. 88, 1954]

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TABLE 1. *Initial Composition of Soils; Rates and Composition of Liming Materials*

Centre	Soils at start of experiment				Liming materials used, and their CaO and MgO contents								Soil association[3]
					Calcic				Magnesian				
	pH	CaO[1]	MgO[1]	Total organic matter		Rate, cwt. per acre[2]	CaO	MgO		Rate, cwt. per acre[2]	CaO	MgO	
				%			%	%			%	%	
Craigiebuckler .	5·3	100	6	12	Ground burnt lime	17·5 and 35	87·5	2·3	Ground burnt magnesian lime	17·5 and 35	48·0	31·8	Countesswells freely-drained
Wedderhill II .	5·0	250	27	25	Ground limestone	30	51·7	1·8	Ground burnt magnesian lime	30	48·0	31·8	Countesswells freely-drained with humus top
Sunnybrae .	5·1	120	5	8	Ground limestone	30	47·8	2·4	Ground magnesian limestone	30	31·2	20·0	Countesswells poorly-drained
Drimmies . .	5·8	220	14	10	Ground limestone	30	47·8	2·4	Ground magnesian limestone	30	31·2	20·0	Tarves freely-drained
Ardtannes . .	5·3	170	6	10	Ground limestone	20 and 40	47·8	2·4	Ground magnesian limestone	20 and 40	31·2	20·0	Tarves freely-drained

[1] The CaO and MgO values for soil were obtained by extracting 20 g. of air-dry soil (< 2 mm.) with 800 ml. 2·5 per cent. acetic acid for 2 hours, and are stated as mg. per 100 g. soil.

[2] The materials were applied on the basis of their total (CaO and MgO) neutralizing values, but for convenience in the table these are stated as the equivalent CaO.

[3] These soil associations are described in the annual reports of the Macaulay Institute, 1939–45.

Duplicate samples were taken from each treatment at every sampling time, after which the grass was cut and removed, yield data being obtained for a number of the cuts.

In all five experiments suitable basal dressings of nitrogen, phosphate, and potash were applied for each crop.

Results

Mangolds, fodder beet, and sugar-beet.—Liming produced very large increases in the yields of all three crops, but the differences between the

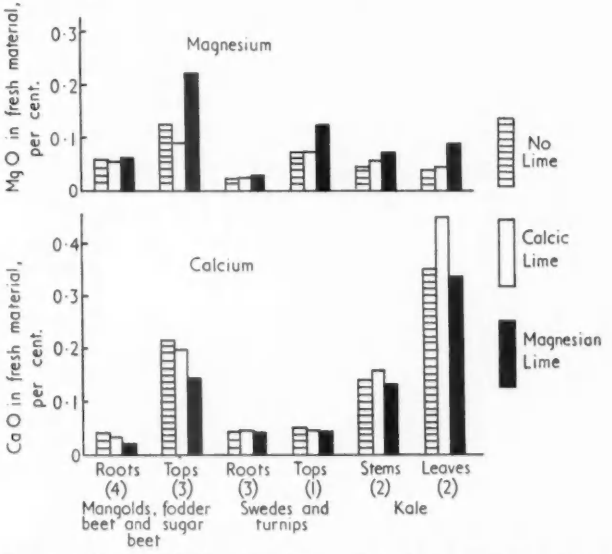

FIG. 1. Effects of liming materials on the calcium and magnesium contents of crops. (The figures in parentheses show the number of samples analysed from each treatment.)

yields produced by the two types of material were insignificant. Although there were quite large variations in the percentages of magnesium and calcium in the roots and tops, the three crops showed practically the same treatment effects and only mean values are therefore presented in Fig. 1. The lime treatments produced much larger effects on the tops than on the roots, and the small differences in the latter were of little significance except with mangold roots at Craigiebuckler. At this centre liming reduced the CaO percentage in the roots from 0·05 to 0·03 but the calcium removal was increased from 3·6 to 13·9 lb. CaO per acre. The percentages of both calcium and magnesium in the tops were reduced by the ground limestone treatment. Magnesian limestone produced tops with a considerably higher magnesium but lower calcium content than those receiving no lime or ground limestone.

Swedes and turnips.—The increases in the yields of these crops produced by liming were quite small. The percentages of magnesium and calcium in the roots were practically the same in the three crops examined and, as can be seen from the mean values in Fig. 1, they showed no effect of the lime treatments. The only noteworthy effect was that magnesian limestone increased the magnesium content of the turnip tops.

Kale.—As with swedes and turnips, liming produced only small increases in yield. The results for stems in Fig. 1 show that ground

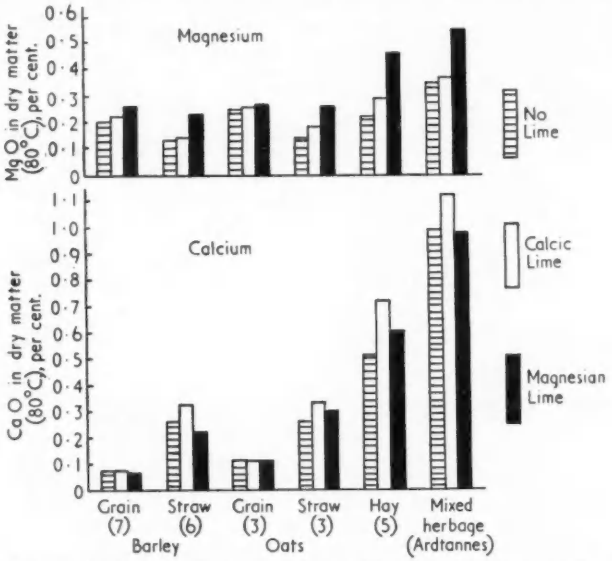

FIG. 2. Effects of liming materials on the calcium and magnesium contents of crops. (The figures in parentheses show the number of samples analysed from each treatment.)

limestone appeared to increase their calcium and magnesium percentages, and that magnesian limestone appeared to increase their magnesium and reduce their calcium contents, but these effects were relatively small and of little significance. Magnesian limestone produced quite a large increase in the magnesium content of the leaves, while ordinary limestone increased their calcium content.

Barley.—Samples from six varieties of barley were analysed: with four of these (Kenia, Maja, Earl, Ymer) liming gave 100 per cent. or more increase in yield, while the fifth (Craig's Triumph) showed a small increase. The yield of the sixth variety, Bere, showed no effect of liming. The variations in the percentages of magnesium and calcium in the grain and straw were quite small and only mean values are given in Fig. 2. With grain the only noteworthy effect was that magnesian liming materials produced a small increase in the magnesium percentages. With straw, magnesian limestone increased the magnesium but slightly

reduced the calcium, while ground limestone had no effect on the magnesium but produced a small increase in calcium.

Oats.—Liming did not give a significant increase in the yields of any of the oat crops in these experiments. The percentages of magnesium and calcium in the grain (Fig. 2) were likewise unaffected by the lime treatments. The magnesium content of oat straw showed an increase

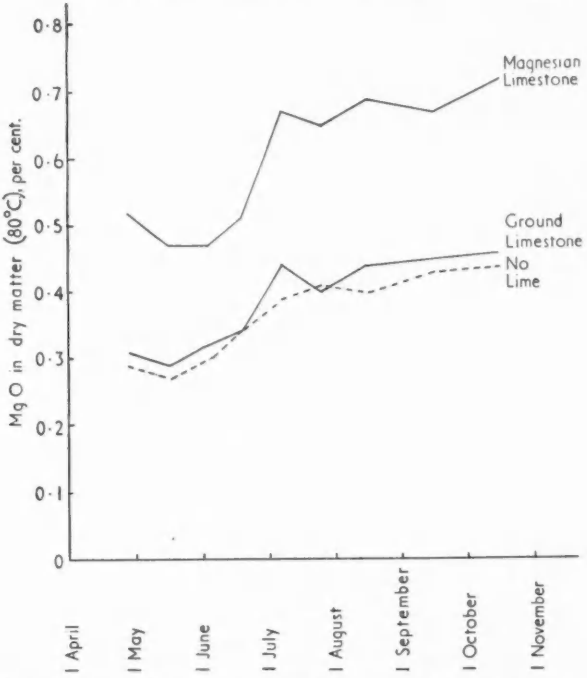

FIG. 3. Effects of lime treatment and time of sampling on the magnesium content of mixed herbage, Ardtannes, 1950–2.

with both materials, magnesian limes nearly doubling it. Although both types of lime tended to produce small increases in the calcium content of the straw these were not large enough to be of any significance.

Hay.—The yields of all five hay crops showed quite large responses to liming but no differences attributable to the forms used. Both types of lime increased the magnesium and calcium contents (Fig. 2): magnesian limes doubled the magnesium content and increased the calcium by about 20 per cent., while calcic materials produced about a 30 per cent. increase in the magnesium and nearly a 50 per cent. increase in the calcium.

Mixed herbage.—The 1-year experiment at Drimmies provided preliminary information on the seasonal variation in the magnesium content of pasture and on the immediate effects of the ground limestone, magne-

sian limestone, and magnesium sulphate treatments. The six cuts showed very similar seasonal effects to those outlined below for the Ardtannes experiment. The mean MgO content of the herbage for no lime, ground limestone, magnesian limestone, and magnesium sulphate was 0·43, 0·41, 0·46, and 0·54 per cent. respectively. Magnesian limestone had no appreciable effect on the magnesium content of the

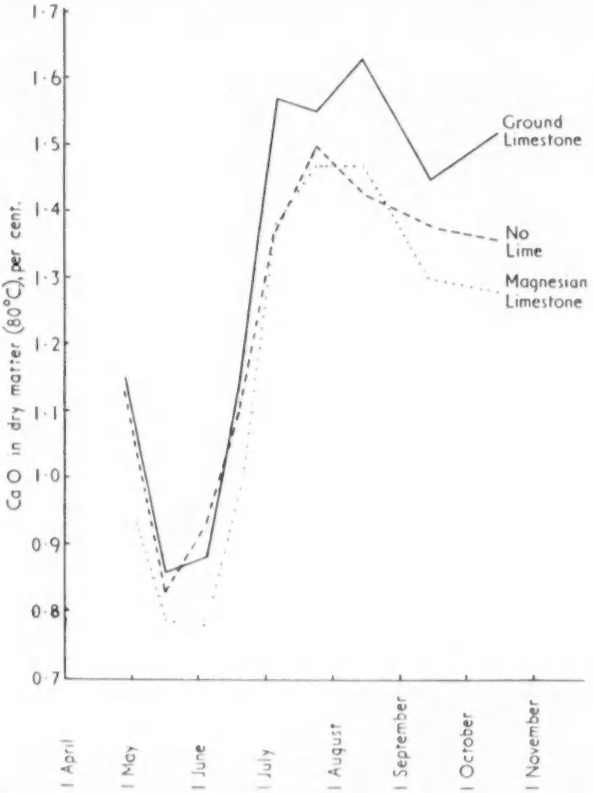

FIG. 4. Effects of lime treatment and time of sampling on the calcium content of mixed herbage, Ardtannes, 1950–2.

pasture during the five months after application. Except for the sixth cut in August, when all four treatments gave similar magnesium values, magnesium sulphate produced a 20 to 28 per cent. increase in the magnesium content of the pasture.

At Ardtannes yield results were obtained for three cuts in 1950 and four in 1951. Although none of the lime treatments produced significant increases in yield at any one cut, in both years the means for the lime treatments were significantly greater than those for no lime. There were

no differences between the yields with ground limestone and magnesian limestone.

The results for the magnesium and calcium contents of the herbage are presented in Figs. 3 and 4. Since with each liming material the MgO and CaO percentages were practically the same for the two rates of application and for all three years only mean values are shown. For instance, in mid-May the magnesium (MgO) percentages for the samples from the no lime and ground limestone treatments were within the range 0·24 to 0·31, while the corresponding range for magnesian limestone was 0·42 to 0·52. Both magnesium and calcium showed a 60 to 100 per cent. variation during the growing season. The magnesium contents of the herbage at the first sampling at the end of April were relatively low while the values for the mid-May and end of May or beginning of June samples were always the lowest. The mid-June and early July samples gave intermediate values and from the third week in July until October the values were fairly high and reasonably constant.

TABLE 2. *Composition of Soils after Treatments Shown (1952)*

Centre	*No lime*			*Calcic limes*			*Magnesian limes*		
	pH	CaO	MgO	*pH*	CaO	MgO	*pH*	CaO	MgO
Craigiebuckler .	5·0	110	4	5·7	210	7	5·7	170	33
Wedderhill II .	4·8	205	15	5·5	430	30	5·4	360	60
Ardtannes. .	4·8	150	7	5·6	260	12	5·6	230	50
Sunnybrae .	5·3	120	6	5·9	240	6	6·3	250	50

The figures for CaO and MgO are in mg. per 100 g. air-dry soil (< 2 mm.).

The differences between the MgO values for no lime and ground limestone were small and insignificant, but magnesian limestone always increased the magnesium content of the herbage, the mean increase over the 3-year period being 55 per cent. This effect is clearly shown by the results for mixed herbage in Fig. 2. It is also noteworthy that the magnesian limestone treatments produced herbage during April, May, and June with MgO contents at least as high as the August, September, and October values for the produce from the no lime and ground limestone treatments. The curves in Fig. 3 show very clearly this difference between the two liming materials.

The seasonal variation in the calcium percentages (Fig. 4) was very similar to that for magnesium, and ground limestone nearly always produced herbage with a slightly higher calcium content than the no lime or magnesian limestone treatments. Although there was occasionally a tendency for the calcium content of the grass from the magnesian limestone treatments to be slightly lower than that for no lime the differences were generally quite small and, as is shown in Fig. 2, the mean values for the 3-year period were practically the same for these two treatments.

The phosphorus, potassium, and sodium contents were estimated in all the samples in order to determine how they were affected by the application of magnesian limestone. The results did not show any large or consistent effects of the liming materials on the percentages of these

elements, the mean values being practically the same for the three main treatments.

Soil effects.—The pH and acetic-soluble CaO and MgO contents of the soils from the various treatments in the four main experiments were determined, and mean values for the samples taken in 1952 are given in Table 2. This shows that both types of liming materials produced similar increases in soil pH values. As might be expected, calcic liming materials generally gave larger increases in the CaO values than did magnesian ones, while the latter produced much bigger increases in the MgO figures than did the former. Except at Wedderhill II, where ground limestone doubled the MgO, the calcic limes had only a small effect on the MgO values.

Discussion

The results show clearly that on the soils studied the application of liming materials rich in magnesium produced quite large increases in the percentage of this nutrient in the leafy parts of plants, but the effect was generally much smaller in the storage parts such as roots and grain. All the calcic materials contained a small amount of magnesium but they had practically no effect on the percentage of this nutrient in the crops. Although magnesian liming materials increased the percentage of magnesium in the tops, leaves, or straw of the crops analysed, their yields showed no response to it. These findings are in agreement with those of other workers [5, 6, 7, 8].

It seems quite clear that the ratio of calcium to magnesium in the soil can vary within quite wide limits without affecting crop yields, and that the magnesium content of produce depends to a large extent on this ratio. It is also clear that a fairly heavy application of a magnesian supplement to the soil is required to bring about any marked increase in the magnesium content of crops.

The pasture results showed that on these Scottish soils there was a considerable variation in the magnesium content of the herbage throughout the growing season. In agreement with the findings of Stewart and Holmes [9], Ferguson [10], and Cooper *et al.* [11], the magnesium content of pasture was lowest during May and early June. There was a gradual rise in the percentage of this nutrient until the end of July after which it remained reasonably constant. It is necessary to remember that this seasonal variation was obtained with samples of herbage taken at regular intervals of 2 to 4 weeks in order to obtain produce similar to that which stock would be grazing. It is quite possible that a different result might be obtained with another sampling technique. The results showed conclusively that the application of liming materials rich in magnesium can give herbage containing about 50 to 60 per cent. more magnesium than either no lime or calcic liming materials. This agrees with the findings of Bartlett *et al.* [3] who used magnesite. The Edinburgh and East of Scotland College of Agriculture [12] has shown that spraying pasture with 10 to 20 lb. magnesium sulphate per acre also produces a marked increase in its magnesium content, but the effect of this treatment lasted only for a few weeks. The cost of applying magne-

sian limestone is relatively low and the effect of such treatment lasts for a number of years.

Summary

A range of crops was grown in five field experiments involving treatments with calcic and magnesian liming materials, and the effect of these treatments on the amounts of calcium and magnesium in the crops was determined.

The results showed that applying limes rich in magnesium produced quite large increases in the percentage of this nutrient in the tops of mangolds, fodder beet, sugar-beet, and turnips, in the leaves of kale, in cereal straw, and in hay. The magnesium contents of the roots, stems, and grains were practically unaffected by the types of liming material used.

With mixed herbage cut at regular intervals of 2 to 4 weeks, there was a 60 to 100 per cent. variation in the percentage of calcium and magnesium during the growing season. These values were relatively low during April, May, and early June, and gradually increased until August, after which they remained reasonably constant. Over a 3-year period magnesian limestone increased the magnesium content of mixed herbage throughout the growing season by 55 per cent. as compared with no lime or ordinary ground limestone.

Acknowledgements.—The writer makes grateful acknowledgement to Professor A. B. Stewart and Dr. E. G. Williams for advice and suggestions, and to all his colleagues who assisted with the field and laboratory work.

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(*Received 10 August 1954*)

A COMPARISON OF THE EFFECTS OF ORGANIC AND INORGANIC FERTILIZERS ON THE GROWTH AND YIELD OF POTATOES

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THE value of farmyard manure and compost is generally attributed to their function as soil conditioners as well as to the inorganic plant nutrients which they supply. It is, however, still uncertain whether such manures owe part of their value to substances, not necessarily essential for plant growth, but capable of stimulating growth when supplied in minute quantities. It is known, for example, that the growth substance β-indolyl-acetic acid is present in soils and animal manures [1], and that soil micro-organisms produce appreciable quantities of this substance [2]. Despite many claims, there is still no convincing evidence that application of the pure salt of this compound to soil or sand cultures results in significant increases in plant growth. Farmyard manure may also supply appreciable amounts of essential trace elements.

An attempt has been made, by means of short-term growth studies in the field, to ascertain whether there is evidence for the presence of growth factors in a soil manured with compost which are not supplied by a soil receiving commercial inorganic fertilizers containing nitrogen, phosphorus, and potassium.

Method of Study.—The basis upon which a direct comparison may be made affords some difficulty. Indeed, considered in terms of crop yield, it might seem that a valid comparison could not be made by simple field trials, on account of the differences which must occur between treatments in the availability of nitrogen, phosphorus, and potassium.

If accessory growth substances, whether organic or inorganic in nature, are supplied by compost, then their effect on the plant should be evident in the earliest stages of growth when the supply of N, P, and K is most likely to be adequate. Similarly, at that time, any immediate amelioration of the physical condition of the soil by the dressing of organic matter might also be expected to influence growth, as compared with the growth of plants receiving inorganic fertilizers only. A comparison has therefore been made of the relative growth rates of potato plants receiving differential fertilizer treatments.

The experiment was thus not designed to make a direct comparison in terms of plant nutrients between an organic compost and soluble inorganic salts. The aim when supplying the manurial dressings was to maintain the major nutrients at a sufficiently high level to prevent their becoming limiting factors in the earlier stages of the growth of the plant.

Compost was prepared on the lines recommended by Howard [3],

[Empire Journ. of Exper. Agric., Vol. 22, No. 88, 1954]

and included poultry and cow manure, fresh green herbage, and vegetable waste from the garden. The finished compost was analysed chemically for its total content of N, P, and K, and equal quantities of total N, P, and K were applied to all plots, whatever the form of the manure or fertilizer. This basis of application was convenient for long-term studies, but, as pointed out above, it had no especial significance in the work to be reported in the present paper. When this method is followed, there is some danger of applying such quantities of inorganic salts as may prove detrimental to the growth of young plants. Account was taken of this possibility in assessing the significance of the growth results.

Experimental Methods

Twelve plots were laid out at Wye in four randomized blocks, on a clay-loam soil containing 18 per cent. $CaCO_3$ (D.M. basis) and having a pH of 8·0. The total nitrogen content was 0·2 per cent. (D.M. basis), and Morgan's extract (1 soil: 2 extractant) gave values for P and K of 4 and 23 p.p.m. respectively.

The plots measured 14×2 yds. and were separated by 1-ft. grass paths. Sixty-four potato plants were grown in each plot.

Manurial treatments.—The following three manurial treatments, replicated fourfold, were applied:

C: Compost prepared from organic residues.

A: Commercial inorganic fertilizers applied at the same rates of total N, P, and K as for C.

$\frac{1}{2}C\frac{1}{2}A$: One-half of the total N, P, and K applied as compost and one-half as inorganic fertilizers.

In the first 3 years the manures were spread on the plots immediately before planting and forked into the soil. In the fourth year the manures were applied as three top-dressings, 2, 7, and 10 weeks after planting.

Advantage was taken of the fact that the precise quantities of manures applied were of no great moment, to make empirical adjustments to the quantities and ratios of N, P, and K applied in successive seasons and so to avoid the danger of applying too much fertilizer to the young plants. The use of hoof-and-horn meal as a supplement to the compost in 1953, and the application of fertilizers as top-dressings, were attempts to increase the level of available nitrogen in all treatments while avoiding the detrimental effects of high dressings of inorganic salts. The manurial dressings applied are shown in Table 1.

Plant material.—The crop studied was the potato variety King Edward VII, which was suitable also for studies of disease incidence which will be reported elsewhere. In 1950 stock-certified Scottish seed tubers were planted, and in this and each of the succeeding 2 years two tubers were saved for seed from every plant free from the symptoms of virus disease at the end of the season. Plants were thus grown continuously in the same plots for 4 years. By the end of the 1953 season all plants showed symptoms of severe mosaic but no leaf roll appeared in that year.

The numbers of plants showing symptoms of virus infection in 1953 did not differ significantly between treatments.

Growth measurements.—The initial problem was to determine whether, at any stage of growth, plants receiving only organic manure showed a higher growth rate than those receiving either inorganic fertilizers only or a mixture of the two. It was not practicable to make dry-matter determinations on whole plant samples at frequent intervals and still to retain sufficient plants to assess yield and disease incidence with precision. Growth measurements were therefore confined to the height

TABLE 1. *Manurial Treatments in Different Years*

(*tons or cwt. per acre*)

Treatment	*Fertilizer or manure*	*Base dressings*			*As 3 top-dressings*
		1950	*1951*	*1952*	*1953*
A	Sulphate of ammonia (cwt.) (20·6% N)	13·0	10·0	10·0	11·1
	Superphosphate (cwt.) (16% P_2O_5)	23·8	15·7	17·6	7·9
	Sulphate of potash (cwt.) (48·6% K_2O)	4·6	6·2	9·7	2·9
C	Hoof-and-horn meal (cwt.) (13% N, 2·5% P_2O_5)	..	..	..	12·1
	Compost (tons)	27·0	14·9	10·6	5·8
	Analyses of compost (*as % D.M.*)				
N		0·94	1·33	1·76	1 29
P_2O_5		1·50	1·62	2·38	1·71
K_2O		0·77	1·94	4·02	2·63
Loss on Ignition		27·7	30·5	57·7	31·3

of the primary stems. Records were taken of the date of appearance of plants above ground, and thereafter weekly height measurements were made on the stems of seven marked plants on each plot.

The tubers were lifted each year in September and the fresh weights of the washed tubers were determined. The water content of the tubers was estimated by drying samples with a forced draught at 100° C. for 24 hrs. N, P, K, Mg, and Ca determinations were carried out on the dried material.

In 1950 and 1951 nitrogen determinations were made on leaflet samples throughout the season.

Experimental Results

Emergence of Shoots.—Sprouted seed tubers were planted on 27–28 March in each season, and counts were made twice weekly of the numbers of plants showing leaves above ground, until emergence was complete.

In no year were there significant differences between treatments for final plant numbers. There were, however, differences in the rate of emergence of plants above ground. In 1950, from 3 to 10 May, plant numbers for treatment A were significantly less than for treatments C and ½C½A, which did not differ between themselves. Between 8 and 15 May 1951 treatment C produced higher numbers than A, but ½C½A

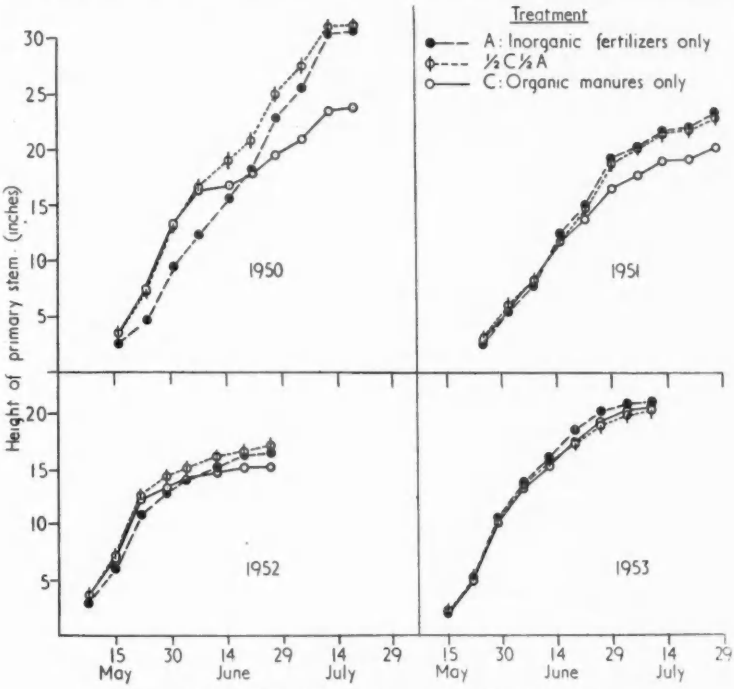

FIG. 1. Growth in height of primary stem of potato plants.

did not differ significantly from either. No differences between treatments appeared in 1952 at any time. In 1953 treatment C was significantly less than ½C½A (28 April to 1 May), and on 1 May only, C was significantly less than A.

Growth of the Primary Stem.—The stem heights for 4 years are summarized graphically in Fig. 1. If the mean relative growth rate (r) be estimated between times T_1 and T_2, then as Fisher [4] has indicated:

$$r = \frac{\log_e H_2 - \log_e H_1}{T_2 - T_1}$$

where H_2 = stem height at time T_2, and H_1 = stem height at time T_1, and this is valid whatever the form of the growth curve. Using this formula, growth rates have been calculated for intervals of 1, 2, and 3

weeks in each season and the full results analysed statistically. The results are dealt with under 'Discussion'.

Nitrogen status of the plants.—The leaves of plants receiving only compost were generally of a paler colour than those of plants receiving inorganic fertilizers. This difference was shown to be associated with a significantly lower content of nitrogen in the leaves of the C series for the greater part of the growing period.

Samples of *leaves* were taken at fortnightly intervals throughout the first two seasons for Kjeldahl determinations of total nitrogen. Seven plants were selected at random from each plot on each sampling occasion, and one leaflet was removed from the distal pair of every leaf on one shoot of each plant. The mean values are shown in Table 2.

TABLE 2. *Nitrogen Content of Leaflet Samples*

(*Percentage on dry matter*)

Date	*1950*			*Date*	*1951*		
	C	½*C*½*A*	*A*		*C*	½*C*½*A*	*A*
	%	%	%		%	%	%
29/5	5·17	6·03	5·60	25/5	5·16	4·85	5·27
12/6	4·47	5·34	5·29	8/6	4·64	4·94	4·87
26/6	4·02	4·95	5·17	22/6	4·25	4·67	5·09
10/7	3·68	4·30	4·83	6/7	3·92	4·38	4·42
24/7	2·86	3·90	4·26	20/7	3·86	4·20	4·12
8/8	2·27	3·29	3·97	3/8	3·15	3·58	3·69
25/8	1·99	2·81	3·54	17/8	2·81	3·38	3·49
				31/8	4·18[1]	4·15[1]	4·72[1]

[1] Old leaves shed, only young leaves in sample.

The relationship between nitrogen content and time could be expressed by linear regression equations as follows:

Treatment

C: $y = 5{\cdot}07 - 0{\cdot}037\ x_1$; $y = 5{\cdot}09 - 0{\cdot}027\ x_2$;

½C½A: $y = 5{\cdot}91 - 0{\cdot}037\ x_1$; $y = 5{\cdot}10 - 0{\cdot}019\ x_2$;

A: $y = 5{\cdot}68 - 0{\cdot}024\ x_1$; $y = 5{\cdot}35 - 0{\cdot}022\ x_2$;

where y = percentage nitrogen content of leaflets on dry-matter basis;

x_1 = number of days after 29 May 1950;

x_2 = number of days after 25 May 1951.

In 1950 the regression coefficient for the A series was significantly less (i.e. the nitrogen content decreased less rapidly) than with the other treatments, but in 1951 the regression coefficients did not differ significantly. Comparison of the regression lines for the 2 years shows clearly that the level of nitrogen in the leaves of the C series in 1950 was unusually low from about mid-June onwards; that is to say, immediately after the fall in growth rate of the stem became manifest (see Fig. 1).

From the regression equations for nitrogen content of leaflets, the

value which coincides with the check to stem growth seen in Fig. 1 may be calculated for the C series. In 1950 the check began on 7 June, when the calculated nitrogen content of the leaflet sample was 4·74 per cent., and in 1951 the check began on 15 June, when the calculated nitrogen content of the leaflet sample was 4·53 per cent. The nitrogen content of leaves of plants receiving inorganic fertilizers did not fall to comparable values for some weeks after these dates.

TABLE 3. *Water and Nitrogen Content of Tubers*

	1950			*1951*		
	C	½*C*½*A*	*A*	*C*	½*C*½*A*	*A*
	%	%	%	%	%	%
Water (on fresh wt.)	75·8	77·3	78·2	73·2	74·1	76·0
N (on dry wt.)	1·14	1·48	1·73	1·26	1·50	1·66
	1952			*1953*		
	C	½*C*½*A*	*A*	*C*	½*C*½*A*	*A*
	%	%	%	%	%	%
Water (on fresh wt.)	74·0	75·6	74·5	78·4	78·4	78·6
N (on dry wt.)	1·13	1·58	1·63	1·69	1·88	1·84

In Table 3 is shown the water and nitrogen content of the *tubers* at lifting. All differences between treatments for percentage nitrogen content of tubers were found to be significant at the 1 per cent. level in the first two seasons (calculated from angular transformation of percentages). Analyses in later seasons were carried out on bulked samples. The results provided further evidence for the low nitrogen status of plants in the C series.

TABLE 4. *Yield of Tubers*

(*Tons per acre*)

Treatment	*1950*		*1951*		*1952*		*1953*		*Mean*	
	Fresh	*Dry*	*Fresh*	*Dry*	*Fresh*	*Dry*	*Fresh*	*Dry*	*Fresh*	*Dry*
C	10·37	2·52	8·84	2·37	4·69	1·23	9·43	2·02	8·33	2·04
½C½A	15·95	3·61	12·19	3·16	5·98	1·48	9·29	2·02	10·85	2·57
A	15·46	3·36	11·56	2·76	5·48	1·38	9·00	1·93	10·38	2·36
L.S.D. (P = 0·05)	1·14	0·40	0·94	0·35	0·74	Differences not significant			..	..

Yield of tubers.—The yield results are summarized in Table 4. The difference in yield between the C and A series tended to become less with the years, and in the fourth season it did not reach significance. In general the differences in tuber yield were similar to those for height growth.

Observations on disease incidence, both in the tubers and in the leaves, suggested that the trends in yield data could not be attributed

primarily to differences in the incidence of virus or fungus diseases in the three treatments, despite the fact that no fungicides were employed and the tubers were returned to the same plots year after year. Thus the most severe attack of blight occurred in 1950 and the greatest incidence

TABLE 5. *Nitrogen and Mineral Content of Tubers*

(*Percentage on dry matter*)

Treatment	*N*	*P*	*K*	*Mg*	*Ca*[1]
C . . .	1·31	0·22	2·09	0·07	0·11
½C½A . .	1·61	0·20	2·16	0·08	0·14
A . . .	1·72	0·19	2·17	0·08	0·11

[1] Ca results for 1950 and 1953 only.

of virus diseases in 1953. The low yields of 1952 may be related to the fact that this was the driest and sunniest year. Meteorological factors and nitrogen uptake would appear to have been mainly responsible for the variations in yield.

TABLE 6. *Uptake of N, P, and K by Tubers*

(*lb./acre*)

Nutrient	*Year*	*Amount supplied*	*Amount taken up*		
			C	½*C*½*A*	*A*
Nitrogen	1950	299	62	118	128
	1951	230	67	105	104
	1952	230	31	52	50
	1953	256	76	85	80
	Mean	254	59	90	91
Phosphorus	1950	187	12	16	14
	1951	123	10	14	10
	1952	138	5	7	5
	1953	62	12	10	10
	Mean	128	10	12	10
Potassium	1950	207	116	170	159
	1951	282	99	130	118
	1952	439	59	76	71
	1953	135	100	106	100
	Mean	266	94	121	112

Nitrogen and mineral content of tubers.—Analyses were carried out on bulked samples. Except for nitrogen, the effect of treatment was slight. Mean values for the 4 years are shown in Table 5.

The uptake of N, P, and K by tubers was calculated from the yield and analytical data. (Note that P and K are expressed as elements, not as oxides.) In Table 6 the mean values are presented together with the quantities supplied annually as fertilizer or manure.

Discussion

For the growth measurements three types of result might provide evidence for the special value of compost: namely, where: (1) C gave a higher growth rate than A; (2) C gave a higher growth rate than $\frac{1}{2}C\frac{1}{2}A$; (3) $\frac{1}{2}C\frac{1}{2}A$ gave a higher growth rate than A.

Examination of the results showed that the first type of result was observed for the emergence of shoots on the first three counts made in both 1950 and 1951, and for the stem height in 1950 only, on three occasions (24 and 31 May and 7 June); but it did not hold good for the mean relative growth rate of the stem at any time. The stem-height differences may thus have been due to differences in the growth of the shoots before emergence at ground level.

On no occasion and over no period did plants grown with compost only (C) have a higher growth rate, or a greater plant number on emergence, than plants receiving the mixed manures ($\frac{1}{2}C\frac{1}{2}A$).

The third type of result ($\frac{1}{2}C\frac{1}{2}A > A$) was found for the emergence of shoots in 1950 (first three counts only), and on one occasion in 1951 (15 May), but it did not appear in the growth-rate observations.

Thus compost appeared advantageous only at the earliest stages of growth, in the first two seasons, when the shoot was less than 2 in. above the soil level. From the results it is not possible to distinguish with certainty between a beneficial effect due to compost and a harmful effect associated with the exceptionally heavy dressings of inorganic fertilizers. Whichever of these alternatives was correct, the growth rate of the stem was evidently unaffected by the slight initial advantage enjoyed by plants receiving compost only, at least for 3 weeks following the appearance of all the plants above ground. Three to 4 weeks after stem measurements were started, in 1950, 1951, and 1952, the growth rate of the C series fell significantly below that of the A and $\frac{1}{2}C\frac{1}{2}A$ series. Fig. 1 shows this clearly. This check to growth may be attributed to the lower nitrogen content of the tissues in the C series, to which attention was directed earlier. In 1953, with the compost supplemented with hoof-and-horn meal, no significant differences were found between treatments for either growth rates or final shoot heights.

The effect of compost on shoot emergence noted in 1950 and 1951 was thus transitory and of no apparent significance in the subsequent growth and final yield of the crop. A study of the growth curves in 1950 (Fig. 1) suggested that the high growth rate of the stems in the A series from 15 June to 12 July might be associated with a rapid recovery following an initial check to growth occasioned by the use of more than 2 tons of inorganic salts per acre. Furthermore, the magnitude of the effect on the appearance of plants above ground, associated with compost, was much less marked in 1951 when the total dressing of inorganic salts in the A series was reduced to 32 cwt. per acre.

Manurial dressings were further reduced in 1953, and applied in three separate top-dressings after planting. When this was done, emergence of the plants was more rapid with $\frac{1}{2}C\frac{1}{2}A$ and A than with C, a

result which again suggested that no special benefit was to be attributed to the compost.

The magnesium content of the tubers was relatively low throughout the experiment (Table 5), and in 1952 and 1953 some plants in all treatments showed leaf symptoms of magnesium deficiency, an effect associated with this calcareous soil. There was no indication that compost affected the magnesium content of the tubers.

When compost was supplemented with hoof-and-horn meal (1953) the uptake of N, P, and K by the tubers of the C series was nearly the same as for the A and ½C½A series, although in earlier years C was lower (Table 6). Yields were also similar (Table 4). These results, together with the nitrogen analyses of the leaves in 1950 and 1951, show clearly that with compost the available nitrogen supply was the factor controlling total growth and tuber yield.

Summary

The growth of the shoot and the yield of the potato variety King Edward VII was studied for 4 years in small field plots supplied with organic manures, commercial inorganic fertilizers, or a mixture of the two. 'Seed' tubers were saved and planted annually in the same plots.

When the plants were small, and N, P, and K did not limit growth, no evidence could be found which might be attributed unequivocally to some special beneficial effect of compost. Abnormally heavy dressings of inorganic fertilizers (up to 2 tons per acre) resulted in a temporary check to growth of young plants but without apparent permanent injury.

Analyses of leaves and tubers showed that plants receiving compost had a lower nitrogen content than plants receiving inorganic fertilizers, and this resulted in a premature check to growth and a lower yield.

When compost was supplemented with hoof-and-horn meal, the differences between treatments for stem height, and for yield and uptake of N, P, and K by the tubers was slight.

Acknowledgements.—Sincere thanks are due to Prof. F. G. Gregory for his sympathetic interest and helpful advice, and to Mr. S. C. Pearce of East Malling Research Station for guidance in statistical matters. We are indebted to the staff of the Soil Chemistry Department, N.A.A.S., Wye, for undertaking the compost analyses, and to Mr. G. A. Watson, of the Hop Research Department, Wye College, for mineral analyses of the tubers.

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(Received 21 July 1954; as revised, 30 August 1954)

A TILLAGE STUDY IN KENYA COFFEE

PART II. THE EFFECTS OF TILLAGE PRACTICES ON THE STRUCTURE OF THE SOIL

H. C. PEREIRA[1] AND P. A. JONES[2]

WITH PLATES 6 AND 7

DETAILS of the laboratory methods used in this study of soil structure have been described and discussed separately [1]. The present paper reports the effects on soil structure of the tillage treatments detailed in Part I (this Journal, 1954, **22**, 231), in terms of these various tests.

The surface soil in the area of the experiments contained 63 per cent. of clay, 25 per cent. of silt, and 12 per cent. of sand; gravel was absent. The soil became slightly heavier with depth, the clay content rising steadily to 72 per cent. at a depth of 10 ft. The original forest top-soil in this area was probably 2 to 3 ft. thick; most of this has been lost by cultivation, leaving only from 3 to 9 in. of clearly differentiated top-soil. All of the structural measurements reported here were taken in the first 3 in. In this top-soil weed-growth and leaf-fall from the unshaded coffee have maintained the content of organic matter at approximately $4\frac{1}{2}$ per cent.

Field observations of soil surface effects.—The largest structural differences visible in the field were produced by the weed-control treatments, whose effects have been consistent throughout the 5 years of this experiment. The W_2 plots, on which tall weed growth was permitted in each rains, had the most cloddy surfaces after cultivation; these clods disintegrated readily underfoot but were not easily destroyed by rain. The W_0 plots, clean weeded by cultivation, had smaller and harder soil clods in dry weather, but these clods vanished during very heavy rains. In the fifth year of the trial, scores were allotted by eye-estimation of the signs of surface wash after intensive rain. All the W_0 plots showed substantial sheet erosion, which appeared to be more severe after mechanical cultivation than after hand forking. On the steeper W_0 plots, with slopes up to 8 per cent., soil was washed into the narrow-based terraces. The W_1 plots, on which weeds were slashed, showed signs of considerable loss of water into the terrace-ditches, but soil movement was slight. The W_2 plots showed no signs of soil loss, since in all rainy seasons a continuous soil cover developed between the trees wherever the treatments permitted weed growth. As mentioned in Part I, the vigour and density of weed growth declined under frequent cultivations, but showed no sign of decline under the W_2 treatments.

Sampling methods.—The twenty-seven main plots which received no

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[Empire Journ. of Exper. Agric., Vol. 22, No. 88, 1954]

subsoiling were sampled in 1948, 1949, 1950, and 1951, by both volumetric and composite-sampling methods. A sleeved core-sampler 4 in. in diameter and 3 in. deep was used to take three cores per plot, giving eighty-one per annum. Three disturbed samples, taken near each core, were mixed to give a composite sample for comparison with the core. All sampling was done in dry weather when the surface soil was at or below wilting point.

The depth-of-tillage contrasts, designed primarily to test the effects of implements on the surface roots of the coffee trees, did not extend into the subsoil. Depth of working of the surface tilth was found to have no significant effects whatever on any of the structure measurements made in the first 3 in. The sampling thus gave nine effective replications of the 3×3 set of weed-control and implement treatments.

Clod sieving.—After 5 years of tillage contrasts, a direct field assessment of the proportion of surface soil left in clods in the dry season was made by the hand-sieving technique described by Keen [2].

Laboratory determinations.—Cores were wetted under partial vacuum and drained on tension plates to measure their 'non-capillary' or free-draining pore space; after static-head percolation tests the cores were oven dried and the real volume of soil was determined by displacement in water. The disturbed samples were dry-sieved, and the crumb-fractions weighed and subsampled for wet-sieving, using a mechanical oscillator. Organic matter was determined on numerous samples of both dry and water-stable crumbs. In 1951 both cores and disturbed samples were subjected to artificial rainfall [3].

Experimental Results

The effects of clean-weeding on soil structure.—The structural differences are adequately represented by a summary of the results for the most detailed set of tests, made in 1951 (Table 1). The ten seasons of weed growth produced visible differences between the amounts of fibrous root material in the surface soil of clean-weeded and of weedy plots. While giving valuable increases in crop yield, the clean weeding caused significant reductions in the ability of the surface soil to accept and to transmit rainfall. This is shown clearly and consistently by the various volumetric measurements on soil cores, in which the clean weeding significantly reduced both free-draining and total pore space, and also reduced percolation rates both under rainfall impact and under a static head of water.

Measurements on disturbed tilth are more arbitrary in principle and more dependent on the details of technique. The proportion of soil in large clods was significantly increased by the intensive cultivations. In spite of the roughness of the surface thus produced, these clods were readily shattered by rainfall to give significantly lower percolation rates in the first 3 in. of soil (Table 1, col. 7).

The cleaning cultivations greatly reduced the amount of root-fibre in the surface soil. In the root-free clods the lateritic clay acted as a fairly strong cement while they were handled in the dry state. Clods

TABLE 1. *Structure Effects of Weed-control Cultivations on a Lateritic Soil*

(0–3 in. surface soil, January 1951, after eight cycles of cultivation contrasts)
(Means of twenty-seven soil cores or samples from each weed-control treatment)

1	2	3	4	5	6	7	8	9	10	11	12
			Measurements on sleeved soil cores				*Measurements on disturbed tilth*				
			Pore space, % of total soil volume		*Percolation, inches per hour*		*Dry-sieving fractions, % of whole soil*		*Water-stable aggregates greater than 0·5 mm., % of whole soil*		
Field treatment		*Crop yield, 5-year totals, cwt. clean coffee per acre*	*Total pore space*	*Pores drained at 50 cm. water tension*	*Under 1 cm. static head*	*Artificial rain at 6 in. per hour*	*Clods over 1¼ cm. diameter*	*Soil passing 0·5 mm. diameter sieve*	*After vacuum-wetting*	*After immersion-wetting*	*After rain-impact wetting*
W_0 Clean weeded		35·29	63·7	19·9	9·8	4·4	31·3	44·2	41·2	24·8	27·9
W_1 Slashed weeds		25·65	65·1	23·0	10·3	5·0	22·6	46·8	41·9	27·9	30·8
W_2 Tall weeds		20·65	65·8	24·4	15·6	5·1	19·3	45·3	40·3	28·9	31·2
Least Sig. Diff.:											
* at P = 0·05		..	0·7	1·6	5·6	..	3·7	4·3	3·9	5·3	3·1
† at P = 0·01		..	0·9	2·1	7·8	..	5·2	..	..	..	..
‡ at P = 0·001		2·56	1·1	2·8	..	0·5	7·4	..	..	..	..
Sig. effects		$W_0 > W_1$‡	$W_0 < W_1$‡	$W_0 <$	$W_0 < W_2$*	$W_0 <$	$W_0 >$	N.S.D.	N.S.D.	N.S.D.	$W_0 < W_2$*
		$W_1 > W_2$‡	$W_1 < W_2$*	W_1, W_2‡		W_1, W_2‡	W_1, W_2‡				

visibly richer in roots and other organic matter proved more fragile when sieved dry. A positive correlation, significant at the 5 per cent. level, was found between the plot yields and clod measurements, but this merely reflects the parallel and apparently independent effects of reduced weed population on trees and on soil respectively. The proportions of clods were not matched by the proportions of fine dusty soil passing the

TABLE 2. *Seasonal Effects of Implements on Porosity of Tilth*

(*Clean-weeded plots*)

Year	*1949*	*1950*	*1951*
TOTAL PORE SPACE (% VOLUME)			
Hand hoe	65·9	65·0	64·4
Disk	64·4	63·1	63·7
Plough	63·2	63·3	63·1
Replication	27	9	27
Least Sig. Diff. at P = 0·05	1·2	1·2	1·1
NON-CAPILLARY PORE SPACE (% VOLUME)[1]			
Hand hoe	22·4	21·9	25·4
Disk	21·4	20·4	23·8
Plough	18·3	18·4	22·9
Replication	18	9	27
Least Sig. Diff. at P = 0·05	3·2	3·5	1·4
PERCOLATION RATES, INCHES PER HOUR[2]			
Hand hoe	24·3	16·0	12·3
Disk	16·9	13·9	12·4
Plough	13·0	10·7	11·0
Replication	18	9	27
Least Sig. Diff. at P = 0·05	5·4	4·5	5·6

[1] Drained at tension of 100 cm. water. [2] Under 1 cm. head.

0·5-mm. mesh. While the over-cultivated soils looked more dusty, the mechanical dry sieving gave no significant differences between the three levels of weed control, in spite of the high replication provided by eighty-one composite samples (Table 1, col. 9). None of the tillage implements used had a violently shattering effect on the soil.

The water stability of soil aggregates over 0·5 mm. in diameter was improved by the vigorous weed growth. Columns 10, 11, and 12 of Table 1 show that this increased water stability was due principally to an increase in resistance to the stresses of wetting. Removal of the air before wetting the samples gave a minimum of disruption, and very clean soil granules were produced. These granules then showed no significant differences in their resistance to breakdown during mechanical sieving under water. Wetting by immersion also failed to distinguish between these soil conditions, but violent wetting, in an apparatus delivering heavy artificial rainfall at controlled rates [3], gave a difference significant at the 5 per cent. level.

Effects of implements on soil pore space.—While weed-control effects were consistent, implement effects showed much seasonal variation, due probably to the varying soil moisture contents and stages of weed growth at which cultivations were done. Table 2 shows the seasonal variation of implement effects on the pore space and percolation rates of the soil. The results given are for the clean-weeded plots only, since in these plots the implements were used most frequently.

The total pore space showed very small changes, but that resulting from hand forking was significantly better than that produced by disking or ploughing. The freely drained pore space showed greater seasonal variation in its mean value but gave implement effects consistently in the same order, the plough giving the least and the forked hand hoe the most

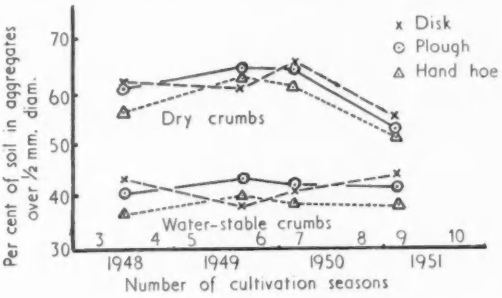

FIG. 1. Effects of tillage implements on soil aggregation in the clean-weeded treatments.

porous tilth. Although the differences in pore space were not large, the resulting differences in percolation rates through soil cores were at first very substantial; these differences declined as the experiment progressed, and by 1951 had ceased to reach statistical significance. The plantation had received only light hand-tillage for some years before 1945, and the average level of cultivation achieved by the experimental treatments was an intensification of soil disturbance. Under mechanical cultivation the decline in percolation was rapid, while under the hand hoe it was slower, but within 5 years it had reached the same stage. Table 2 shows that significant implement differences persisted in both the total pore space and the free-draining pore space. That these differences in pore space were no longer capable of producing effective differences in percolation rates is a clear indication of the decline in stability of the tilth.

Effects of implements on soil aggregation.—The levels of soil aggregation produced by the three types of tillage implements did not differ greatly, and in spite of the high replication the differences reached statistical significance only in the fifth year of the trial. Fig. 1 shows the proportion of soil in aggregates held by the ½-mm. sieve for the last 4 years of the crop-cycle. The first year's results are omitted because different sieve sizes were then used.

By both dry- and wet-sieving techniques the ploughed treatments showed aggregation levels slightly but consistently higher than those for hand hoeing. Disking gave more variable aggregation, possibly because of the need to use a heavier model of disk-harrow on some occasions in order to achieve the prescribed depth of tillage. In 1951 the disk gave a water-stable aggregation which was significantly greater (at the 5 per cent. level) than that left by the hand hoe. Thus the trend was towards greater aggregation, of both wet and dry soil, after continuous clean weeding with tractor implements as compared with the forked hand hoe.

Field observations suggested that this greater aggregation was due to the pressure exerted by the disks or ploughs. When these were used in a weed-free soil, moulded and compacted clods and fragments were visible, often with one surface glazed by contact with the metal implement. These fragments became hard and brittle when dry, and appeared to be

TABLE 3. *Implement Effects on Water-stable Aggregation of Soil*

(*Per cent. water-stable aggregates* $> 0{\cdot}5$ *mm.*)

Method of wetting of the air-dry sample	*Implement*			*Least Sig. Diff.* ($P = 0{\cdot}05$)
	Forked hand-hoe	*Disk-harrow*	*Mouldboard plough*	
Reduced air-pressure .	38·5	43·7	41·2	3·9
Sudden immersion .	25·3	29·3	27·1	5·3
Artificial rain . .	28·0	31·4	30·4	3·1

secured by the cementing influence of the lateritic clay soil. When gently wetted these mechanically produced granules were surprisingly water-stable, although sudden immersion in water usually caused their disintegration. The dominant importance of the method of wetting, for this soil type, led to the introduction of a new method in 1951. Air-dry crumbs were spread on a $\frac{1}{2}$-mm. sieve, and were subjected to heavy artificial rainfall [3]. The results from three methods of wetting, followed by mechanical wet-sieving, are given in Table 3.

Although the more severe wetting reduced the proportion of surviving water-stable aggregates, the three methods have not changed the order of ranking of the results, the disk giving the highest and the hand hoe the lowest degree of aggregation in each instance.

Discussion

Comparison of the tilths produced by the three types of implements shows a sharp contradiction between the results from the volumetric methods and those from the wet-sieving of aggregates. Field observations emphatically confirm the findings by the volumetric measurements, in that rainfall acceptance was clearly greater on the hand-hoed plots than on those ploughed or disked. The wet-sieving thus gave misleading results for implement comparisons. In the weed-control comparisons, wet-sieving tests comprising nine replicate determinations, each on a

composite of three field samples, failed to distinguish between the three widely different soil conditions either when the soil was gently wetted or when suddenly immersed. The more elaborate method of artificial rainfall was necessary, in order to establish an effect that was shown more significantly by all of the volumetric measurements. The practical value of wet-sieving for this lateritic type of soil appears to be much in doubt. Further evidence on this subject is offered in [1] and [4].

Adaptation of the Rotary Cultivator

Acting on the conclusions of Part I we have tested the commercially available forms of rotary cultivator. Some of these are very satisfactory when used under optimum conditions of soil moisture, but such conditions in the field are of brief duration, and in dry soil excessive pulverization of Kikuyu Red Loam has been measured. In co-operation with the manufacturer's agents, modifications were therefore tested with

TABLE 4. *Tilth Analysis after Rotary Cultivation under Dry Conditions* (*July 1952*)

Tillage implement	*Clods over 1¼ cm.*	*Crumbs over ½ mm.*	*Dust less than ½ mm.*
	%	%	%
Forked hand-hoe	40·4	43·7	16·0
Six standard blades at 100 r.p.m. .	19·8	50·4	29·8
Three standard blades at 80 r.p.m. .	16·4	46·6	37·0
Least Sig. Diff. at P = 0·05 . .		11·8	

the object of reducing rotor speeds and increasing the space between blades. While giving a more cloddy appearance, these modifications were shown by detailed tilth analyses to be unsuccessful in dry weather.

A comparative test was made of the forked hand hoe, a standard tractor-mounted rotary cultivator, and a modified implement having fewer hoes and a lower rate of rotation. The tests were carried out in July 1952, immediately adjacent to the tillage experiment already described. Tilth samples were taken by random casting of a 2 × 2 ft. wooden frame, from within which the whole of the disturbed tilth layer was gently transferred to paper bags. The tilth analysis followed the method described by Keen [2]. Sieves were of 2½, 1, and ½ in. square mesh, followed by 8 in. diameter round-holed sieves of 5, 3, 1, and ½ mm. sizes.

Table 4 shows that the hand fork produced less dust than did either the standard or the modified rotary cultivation. Since, in this same field, the main tillage trial had shown no significant differences between the hand fork, the plough, and the disk, in the production of dust passing the 0·5-mm. sieve, the present result emphasized the pulverization caused by the rotary machine.

It was thought that the failure of the modifications to reduce the pulverization was due to the form of hoe blades, which caused the clods

to be thrown against the rotor shield and thus to be shattered unnecessarily. This difficulty has been in part overcome by a further modification by the manufacturers, who have greatly reduced the width of the hoe blades. A further series of tests, made under dry conditions in July 1953, compared the forked hand hoe, a standard rotary cultivator, and a modified implement in which fewer and narrower blades rotated more slowly. Table 5 gives the results of the tilth analysis, which show that the modifications achieved considerable success. Because of the low tenacity of tropical laterized clays in general, and the ease with which their clods and crumbs are mechanically shattered, such a tillage implement may have widespread applications to tropical agriculture. Field trials of the continued use of the new blades are in progress. Figs. 2, 3, and 4 (Plates 6 and 7) illustrate the experimental blades and the tilth produced by them.

TABLE 5. *Tilth Analysis of Rotary Hoe Test*

(*Standard and new rotors*)

Implement	*Large clods over 2½-in. sieve*	*Small clods over ½-in. sieve*	*Crumbs over ½-mm. sieve*	*Dust through ½-mm. sieve*
	%	%	%	%
Forked hand hoe . . .	19·11	11·23	39·30	30·36
Standard rotor . . .	11·53	12·83	44·04	31·59
New rotor	22·82	11·17	39·08	26·99
Analysis by angular transformation: Coefficient of variation, %	33	11	9	14
Least Sig. Diff. at				
P = 0·05 . . .	4·93	1·09	3·00	3·44
P = 0·01 . . .	6·66	1·48	4·05	4·65

Notes:

Forked hoe: 4 tines, approx. 9 in. long; weight, approx. 4 lb.

Standard rotor: 6 hoe-blades at 100 r.p.m.

New rotor: 4 narrow blades at 80 r.p.m.

12 replications: cultivation in 6 randomized blocks; two tilth samples (2 × 2 ft.) per plot.

Mean soil moisture content, 20·8%; wilting point, 22% approx.

In both clod and crumb sizes, the new rotor produced results equal to, and not differing significantly from, the hand hoe, while the standard rotor differed significantly (at P = 0·01) from both, giving less large clods and more small clods and crumbs. The dust fraction showed the new rotor as giving significantly less dust than the standard rotor (at P = 0·05), with the hand hoe intermediate, and not differing significantly from either.

Summary

Changes in soil structure brought about by the contrasting tillage practices described in Part I were examined. The effects of treatments were estimated in the field by sieve analyses of soil tilth, and in the laboratory by dry and water-stable crumb tests, by measurements of pore space and percolation rates, and by submitting both soil cores and disturbed soil samples to the impact of artificial rain.

FIG. 2. Experimental blades designed to increase size of clods to reduce dust

FIG. 3. Tilth left by the forked hand-hoe

FIG. 4. Tilth left by modified blades of rotary cultivator

Clean weeding by all three implements, the disk-harrow, mould-board plough, and forked hand hoe, reduced the free-draining pore space, and the rates of infiltration and percolation of rainfall, to the stage at which local sheet erosion became substantial. Weed competition has, however, so far outweighed the beneficial effects of weeds on soil structure that there is as yet no relation between soil structure and coffee yield in this experiment.

Sieve tests for water-stable crumbs gave poor indications of the physical condition of this lateritic clay soil.

An improved form of rotary cultivation implement has been found most promising for weeding coffee in this type of soil, with a minimum shattering of clods, as shown by dry-sieving tests.

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(*Received 20 April 1954*)

UNIFORMITY TRIAL ON GOLD COAST CACAO (A NOTE)

J. GORDON

IN his paper on 'The Spacing of Nigerian Cacao' [1] T. A. Russell quoted from the Report of the Central Cocoa Research Station, Tafo, for 1938–42, the statement that 'There is reason to believe that there is no "best" planting distance for cocoa even in one locality or on one soil type. Random close planting and allowing the trees to thin themselves as they mature is probably the best practice. This is the local method.' As was shown in the Report, this statement originated with the present writer, as one of the conclusions of an unpublished paper entitled, 'Uniformity trial on 269 one-quarter acre plots of cocoa. A preliminary analysis of the relation between yield per plot; number of trees per plot; number of stems per plot; total girth per plot; "shade effect"; pods per stem; and girth per stem.'

This comparatively large block of farmer-planted cocoa was of mixed age and therefore of varying density. It was consequently possible to see rather clearly the trend of yield with increase in tree girth, and to study the relation between tree number per plot and yield.

When the plots were grouped in classes ranging from 25–50 trees per plot to 276–300 trees per plot, in eleven classes, the distribution was markedly asymmetrical, the mode (78 plots), corresponding to the 76–100 trees per plot class, and this class yielded 2,955 pods per plot. This well-defined mode suggested that this tree density may be a natural optimum for Tafo conditions. Further, there was a 'plateau' of yields between densities of (51–75) trees per ¼-acre plot and (151–75) trees per plot, which is consistent with the view expressed in the extract quoted in T. A. Russell's paper. The mean figures for the five best classes were:

Actual		*Calculated*		
Trees per ¼-acre plot	*Pods per ¼-acre plot*	*Trees per acre*	*Approx. spacing, ft.*	*Yield, lb./acre**
68·2	2,758	272·8	12·6 × 12·6	919·5
87·9	2,955	351·6	11·1 × 11·1	984·9
113·5	2,964	454·0	9·8 × 9·8	988·0
136·1	2,738	544·4	9 × 9	912·8
166·9	2,800	667·6	8·1 × 8·1	933·5
			Mean	= 947·7

* at 12 pods per lb. dry cocoa.

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(*Received 17 December 1953; as revised, 6 September 1954*)

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PRINTED IN GREAT BRITAIN